E7.6-10299
CR-146792

(E76-10299) RELATIONSHIPS BETWEEN VEGETATION AND TERRAIN VARIABLES IN SOUTHEASTERN ARIZONA Ph.D. Thesis (Oregon State Univ.) 258 p HC $9.00 CSCL 08F

N76-22620
Unclas
G3/43 00299

E7.6-10299
CR-146792

AN ABSTRACT OF THE THESIS OF

DAVID A. MOUAT for the DOCTOR OF PHILOSOPHY
(Name of student) (Degree)

in Geography presented on ____________
(Major) (Date)

Title: RELATIONSHIPS BETWEEN VEGETATION AND TERRAIN VARIABLES IN SOUTHEASTERN ARIZONA

Abstract approved: ____________________
(Robert Bard)

A study to determine the relationships between plant species and eight terrain variables and between thirty-one vegetation types and the terrain variables was conducted in a 4, 000 square mile area south and east of Tucson, Arizona. The eight terrain variables included elevation, parent material, macrorelief, landform type, drainage density, slope angle, slope aspect, and solar radiation index, a derivative of slope angle and slope aspect. The term "terrain variable" was chosen to describe several easily measured and identified properties of the landscape.

Data was collected from 250 field sample sites which were selected on the basis of parent material and elevation from within the study area. Floristic data collected consisted of a listing of

species at the sampled site and estimates of species cover and prominence. Elevation, parent material, macrorelief, landform type, slope angle, and slope aspect were also determined at each field sample site. Drainage density and solar radiation index were determined in the laboratory.

The data were analyzed qualitatively using graphs and tables in order to determine general associations between the species and terrain variables, and between vegetation types and the terrain variables.

Stepwise discriminant analysis (BMDO 7M) was also used to quantitatively analyze the data. Computer runs employing stepwise discriminant analysis used individual species to discriminate groups of terrain variables and terrain variables to discriminate vegetation types.

Analyses showed that individual species had broader terrain variable amplitudes than did vegetation types. Consequently it is concluded that plant species are not as closely related to terrain variables as are vegetation types. Those species which are most closely related to the terrain variables include *Cercocarpus breviflorus*, *Mortonia scabrella*, *Quercus emoryi*, and *Sporobolus airoides*. Those species which are considered least closely related to the terrain variables include *Acacia constricta*, *Fouquieria splendens*, *Opuntia phaeacantha*, *O. spinosior*, and *Prosopis juliflora*.

Stepwise discriminant analysis showed that elevation and macro-relief were the best discriminants of the vegetation types. Stepwise discriminant analysis defines an "average" set of terrain variables for each vegetation type. It then identifies the set of terrain variables of each field sample site (observation) with one of the "average" sets of terrain variables of a vegetation type regardless of correlation of the vegetation types. Using this method, one-half of the observations were identified with the correct vegetation type. Thus, all eight terrain variables interacting together did not perfectly discriminate the twenty-five vegetation types. Part of the reason for the "failure" was the similarity among vegetation types. I found that many of the incorrect identifications involved closely related vegetation types.

Relationships Between Vegetation and Terrain Variables in Southeastern Arizona

by

David A. Mouat

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

June 1974

APPROVED:

Professor of Geography
in charge of major

Head of Department of Geography

Dean of Graduate School

Date thesis is presented

Typed by Ilene Anderton for David A. Mouat

ACKNOWLEDGEMENTS

I wish to express my appreciation to the National Aeronautics and Space Administration for financial support of the research under NASA Contract NAS 5-21831.

It is difficult to single out one person from all of the many helpful people to especially thank for help and advice in the development of the research from which this thesis was derived. Several gave selflessly of their time and effort. One person, though, who deserves credit and appreciation is Charles E. Poulton. Dr. Poulton shared my feeling of the importance of integrated environmental studies and encouraged me to continue in this field. He also taught me the importance of applied research, the meaning of which has somehow escaped me over the past several years until recently.

The help of Susanne Luetcke is especially appreciated. She aided immensely in the inspiration of this research. She was also especially helpful in the collection of the field data. Her knowledge and love of the Arizona flora was inspirational to the study.

My associates James R. Johnson and Barry J. Schrumpf provided invaluable psychological as well as methodological support for this study. They gladly gave of advice when it was needed.

I would like to thank Dr. William T. Pyott and Mr. David G. Niess for help with the stepwise discriminant analysis programs.

I would especially like to thank my advisor Dr. Robert Bard and Dr. Robert E. Frenkel for diligent effort in reviewing the manuscript, and providing incisive and constructive criticism throughout the research.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

Figure		Page

RELATIONSHIPS BETWEEN TERRAIN VARIABLES AND VEGETATION IN SOUTHERN ARIZONA

I. INTRODUCTION

Statement of Problem

Plant ecological studies are generally considered to fall into two main classes: synecological and autecological studies. The study of structure, development, and causes of distribution of plant communities comprise the science of synecology (Daubenmire, 1968). Plant species tend to be grouped in different combinations forming more or less definite units of vegetation classes (or communities). The individuals within these units are not scattered at random but are distributed in a pattern over the landscape. According to Daubenmire, communities (expressed as discrete vegetational units) are fundamentally the products of interaction between two phenomena: 1) differences in the environmental tolerances (or ecological amplitudes) of the various taxa which comprise the flora, and 2) the heterogeneity of environment (Daubenmire, 1968; p. 3). Autecology is the study of the interrelations between the individual and its environment. Factors of the environment affecting organisms are those variables such as soil and climate, conditions of which intimately affect the organism. Autecological studies are typically concerned

with the fine scale or the detailed: the study of the effect of a specific plant nutrient on a given organism's metabolism or the response of an individual to variations in the light factor. Rarely are plant ecological studies concerned with the relationships of individuals or units of vegetation with macroenvironmental variables as shown on small scale maps and photos (less than 1:10,000); most synecological studies deal with explanation at a larger scale. The former type and scale of study is the prime objective of this thesis.

The need for these types of studies is obvious. The study of relationships between landforms and vegetation is of paramount importance in the understanding and classification of environmental systems. Such studies provide resource planners and managers with an ideal base for gathering information with which to conduct regional planning. Vegetation distribution frequently provides an excellent indicator of geologic variables which may serve as restrictions in land use as well as indications of agricultural potential. Landform variables provide restricted information on a host of other land use potentials. Together, environmental variables including climate and soils information and vegetation present a precise model. Equivalent environments can be determined and a subsequent land conversion potential scheme for a fairly large and diverse area can be adequately presented.

The principal theme of this study is an assessment of the feasibility of utilizing small-scale (less than 1:62,500) aerial and satellite photography in the interpretation of vegetation. Easily recognized images on such photography are physiographic and pedologic variables. The interpretation of vegetation, therefore, can be accomplished only if convergent and associative evidence is directly employed in the interpretation process. In this, the interpreter usually makes his best estimate as to the type of vegetation he encounters. A thorough understanding of the relationships which exist between vegetation and physiographic variables would greatly facilitate the interpretive process.

This study was undertaken to provide much-needed information on the relationships between terrain variables and vegetation as an integral part of a NASA-sponsored remote sensing project in southeast Arizona.[1] The primary purpose of that project is to provide inventory and analysis of natural vegetation in southeast Arizona. The objectives of this thesis research allow for a greater understanding of those natural vegetation resources. They are:

---

[1] Inventory and Monitoring of Natural Vegetation and Related Resources in an Arid Environment - A Comparative Evaluation of ERTS-1 Imagery. Barry J. Schrumpf, James R. Johnson, and David A. Mouat; Rangeland Resources Program, Oregon State University Proposal No. 311.

1) to supply background information for an ecologically based classification of natural resources in an arid and semiarid environment.

2) to classify the vegetation of the area.

3) to assess the correlation between individual plant species and various terrain variables including elevation, parent material, landform type, macrorelief, drainage density, slope angle, slope aspect, and solar radiation (actually a terrain-related variable).

4) to isolate those plant species which might be considered as reliable indicators of the above-mentioned terrain variables.

5) to assess the relationships between the vegetation types determined from the classification and the terrain variables studied.

6) to isolate specific vegetation types which might be considered as reliable indicators of the terrain variables.

Location of the Study Area

The general region of the study area was chosen because it represents an extremely good example of diverse environments in a semiarid region characterized by the Basin and Range physiographic province (Fenneman, 1931). Few other spatially restricted areas

in the United States possess as much diversity in physiography and vegetation in such a small area as does the study area. The economy of the area is based chiefly upon agriculture, cattle ranching, mining, retirement communities, tourism, defense, andastrophysics (the clear air of the desert combined with a low regional population have resulted in the region's being a major center for the location of astronomical observatories.

The study area chosen for this research essentially coincides with an area chosen by previous researchers under NASA contracts. This thesis research was funded by NASA under the Apollo program and later the ERTS program (see footnote 1 on a preceding page).

The area is bounded by: the Santa Cruz River on the west, $31^{\circ}30'$ N. latitude on the south, $32^{\circ}10'$ N. latitude on the north, and $109^{\circ}45'$ W. longitude on the east (see figure 1). Tucson, Willcox, Nogales, and Bisbee coincide approximately with the northwest, northeast, southwest, and southeast corners, respectively, of the study area. While natural boundaries were preferred, they were not available, except for the Santa Cruz River. $109^{\circ}45'$ W. longitude corresponds, roughly, to the middle of the Sulphur Springs valley, a more or less natural boundary. The north and south boundaries were chosen as representing the northern and southern extent of the NASA-supplied high altitude aerial photography coverage.

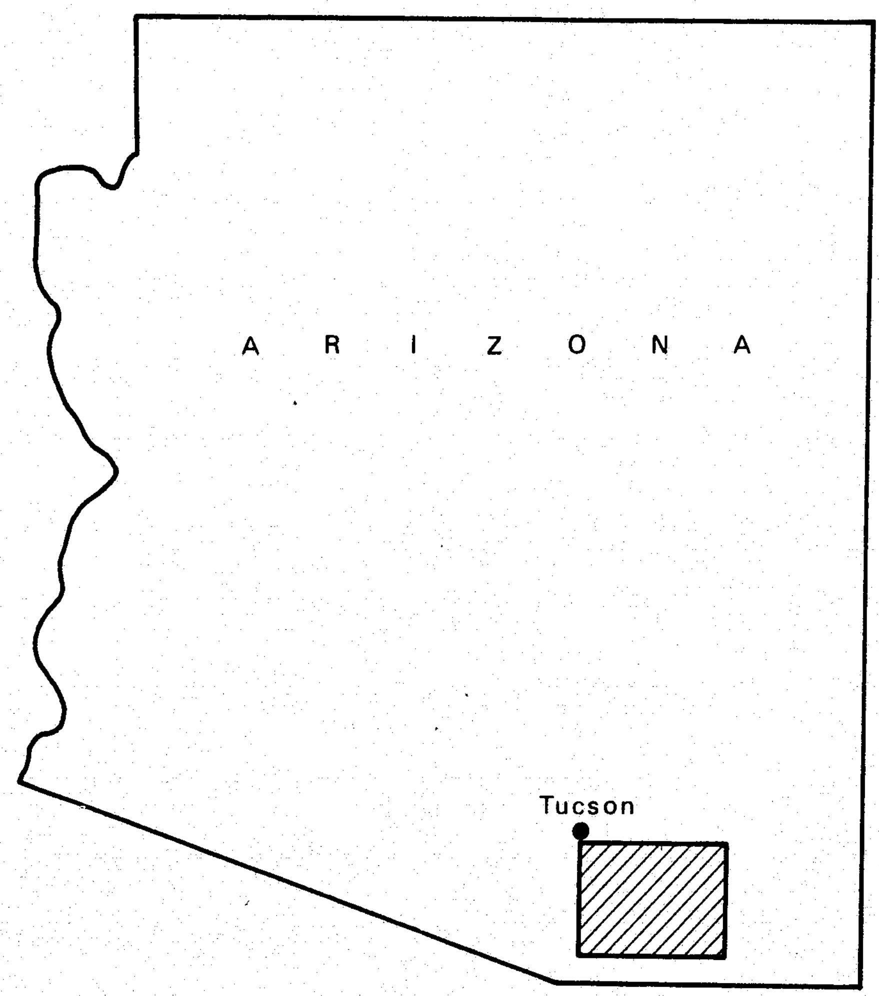


Figure 1. Location of study area (shaded).

II. THE PHYSICAL ENVIRONMENT OF THE STUDY AREA

A knowledge of the physical environment is obviously of considerable importance in understanding relationships between terrain variables and vegetation of an area.

Few components of an ecosystem are totally independent of the other components. Some, such as macroclimate, are not greatly influenced by the other components. A few others, such as geologic structure and lithology, are, perhaps, truly independent variables. Soils are dependent upon a number of variables including parent materials, climate, topography, biotic factors, and, of course, time. Terrain variables and vegetation - the objects of this thesis - are quite dependent upon the other components of the environmental system, including each other. To understand the characteristics and spatial distribution of the terrain variables and the vegetation as well as the relationships of one to the other, it is necessary to discuss the more salient environmental components of the southeastern Arizona landscape.

Climate will be discussed in relation to its controls, how it is influenced by the particular region being studied, and the general nature of several climatic parameters. It must be considered as one of the overriding factors influencing the southeastern Arizona landscape.

The general geology and geomorphology of the study area region will be discussed with respect to the major geologic structure and lithologic controls operative in the region.

Although specific edaphic relationships to vegetation will not be discussed in this thesis, many of the terrain variables reflect edaphic influences. Hence an understanding of the region's soils is felt to be necessary for the understanding of the relationships between terrain variables and vegetation. An attempt will be made to explain the spatial variations of some soil morphological characteristics of the study area.

The vegetation of the study area will be described from the standpoint of previous work on the vegetation and flora of the area. Early, as well as more recent, attempts to classify the vegetation will be reviewed. This will be done in an attempt to present a broad picture of vegetation types based on appearance (physiognomy) as well as broad floristics. Plant species components (with an emphasis on perennial grasses, succulents, and woody species) will be briefly described. The section will also discuss changing vegetation in the study area. The vegetation classification, undertaken by the writer and his colleagues, will be included in the "Methods" chapter.

Climate

The importance of the influence of climate on vegetation of

arid and semiarid regions was summarized well by Hastings and Turner (1965, p. 10):

> Climate remains the single most important determinant for the plant life of an arid region, and to climate one must look to explain the uniqueness of the Sonoran vegetation: to precipitation, its amount, its variability, its spatial and temporal distribution; to temperature; to the various components of the heat balance.

The study area occupies a unique climatic situation in that it is affected by two quite different and distinct air masses and wind circulation systems. In winter, the area is influenced by the southward migration of the westerlies, bringing frontal precipitation. The northward advance of the sun in spring brings with it a northward migration of semi-permanent high pressure systems which tend to block the cyclones embedded in the westerlies. The high pressure known as the "Pacific high" produces an extreme drought in late spring and early summer. At the same time, the Bermuda high is developing in the Atlantic and moves slowly to the west. As both high pressure systems move slowly to the west, the area begins to be affected by the clockwise winds coming around the Bermuda high and bringing with them moist air from the Gulf of Mexico. By the end of May, a tongue of warm moist air intrudes into northeast Mexico occasionally reaching as far as southeast New Mexico. Toward the beginning of July, a global readjustment of the subtropical highs occurs: they move rapidly northward and in so doing a

portion of the Bermuda high breaks off and moves rapidly westward settling over west central United States. Moisture-laden winds coming clockwise around this high from the Gulf of Mexico intrude into southeast Arizona and the Sonoran Desert bringing with them the summer monsoons (Hastings and Turner, 1965). Occasionally, tropical storms spawned in the east Pacific Ocean off Mexico veer northward and move up the Gulf of California. These storms can bring extremely heavy rains to southeast Arizona in late summer and early fall.

Because of the altitude of the study area, ranging from 2, 500 feet to 9, 500 feet, temperatures are moderated somewhat compared to those of the lower desert to the northwest. In addition, annual precipitation figures are higher in the study area than in the lower desert region (Green and Sellers, 1964). Both rainfall and snowfall amounts increase significantly with an increase in elevation. These amounts are most noticeable in the isolated mountain blocks or ranges (the "island mountains") that are interspersed throughout the study area.

The low latitude (31^{o} to 32^{o} N.) of the study area affects the region in two ways: it moderates the region's temperature regime on an annual basis, and situates the study area under the influence of the subtropical highs - the effects of which have already been discussed.

A final climate control, continentality, affects the study area quite markedly. The study area is approximately 400 miles from the Pacific Ocean. Thus storm systems occasionally coming in off the California coast are greatly dissipated by the time they reach the study area. The great distance from the ocean tends to produce a greater seasonal temperature variation.

To illustrate temperature, precipitation, and the annual variability and spatial distribution of temperature and precipitation within the study area, six climate stations within the study area have been selected as being representative of those climatic parameters. The locations of the six stations are shown on Figure 5.

The Tucson station, located at an elevation of 2, 430 feet, is representative of the low desert region extending northwestward for about twenty miles southeast of Tucson. The Benson station is located at an elevation of 3, 575 feet in the north central portion of the study area in the San Pedro Valley. It would typically represent the extensive bajadas and valley fill associated with that drainage. The Cochise station is located at an elevation of 4, 180 feet in the northern Sulphur Springs Valley. Cochise is located adjacent to and west of Willcox Playa - an internally drained basin. The climatic station known as the Santa Rita Range Experiment Station is located at an elevation of 4, 300 feet in the upper bajada west of the Santa Rita Mountains and about 35 miles southeast of Tucson. The Canelo

station is located at an elevation of 4,985 feet in a fairly remote part of the study area in the south central part of the study area west of the Huachuca Mountains. The station is located in a narrow valley, and is fairly typical of the oak woodland - grassland area situated between the Santa Rita and the Huachuca Mountains. The Bisbee station is located near the southeast corner of the study area at an elevation of 5,440 feet. Located in the Mule Mountains, the Bisbee station might be considered as typical of intermediate elevations of the island mountain systems in the study area.

Temperatures of the study area are quite moderate. The hottest temperatures occur on the low desert floor in the vicinity of Tucson. There, summer maxima frequently exceed 100°F and may exceed 110°F. The mean daily maxima in July at Tucson are near 100°F. Those temperatures, though, are ten degrees cooler than stations located further to the west and northwest (for example, Gila Bend). With the exception of Tucson, the highest mean daily maxima occur in the month of June. All stations have a highest mean monthly temperature in July, however. This disparity is due to clear dry nights in June which allow for greater radiation cooling. In July, mean daily maxima drop, but minima rise on account of greater cloudiness and humidity. Mean monthly temperature maxima as well as mean monthly temperatures during the summer months generally decrease with elevation. The highest mean

Monthly maxima at Tucson, 99.6°F in July, and the highest mean monthly temperature, 86.1°F also in July, compare to the 90.0°F average June maxima and 76.5°F average June mean for Bisbee, some 3,000 feet higher in elevation. Temperatures build most rapidly in late spring as Figure 2 illustrates but then taper off gradually through the summer. Winter temperatures are mild with warm days and cool nights, resulting in an extremely popular climate during the winter months. Only a vague relationship exists between elevation and temperature in the winter. Generally, temperature decreases with elevation; however, many stations have warmer temperatures (both mean monthly and mean daily minima during January) than stations at lower elevations. Figure 3, taken from Hastings and Turner (1965), illustrates the point quite well. Note that Benson, Canelo, and Cochise all have lower average daily minima than Bisbee, located at a higher elevation. Those same three stations also have lower record lows and more days per year with minimum temperatures equal to or less than 32°F than Bisbee. Tucson, situated nearly 2,000 feet lower than the Santa Rita Range Experiment Station has a lower January mean daily minimum temperature. The reason for these apparent anomalies is related to cold air drainage. Tucson, Canelo, Benson, and to a lesser extent Cochise, are situated near the lowest point of their respective basins or valleys. Cold night air settles in those low lying areas producing inversions, smog,

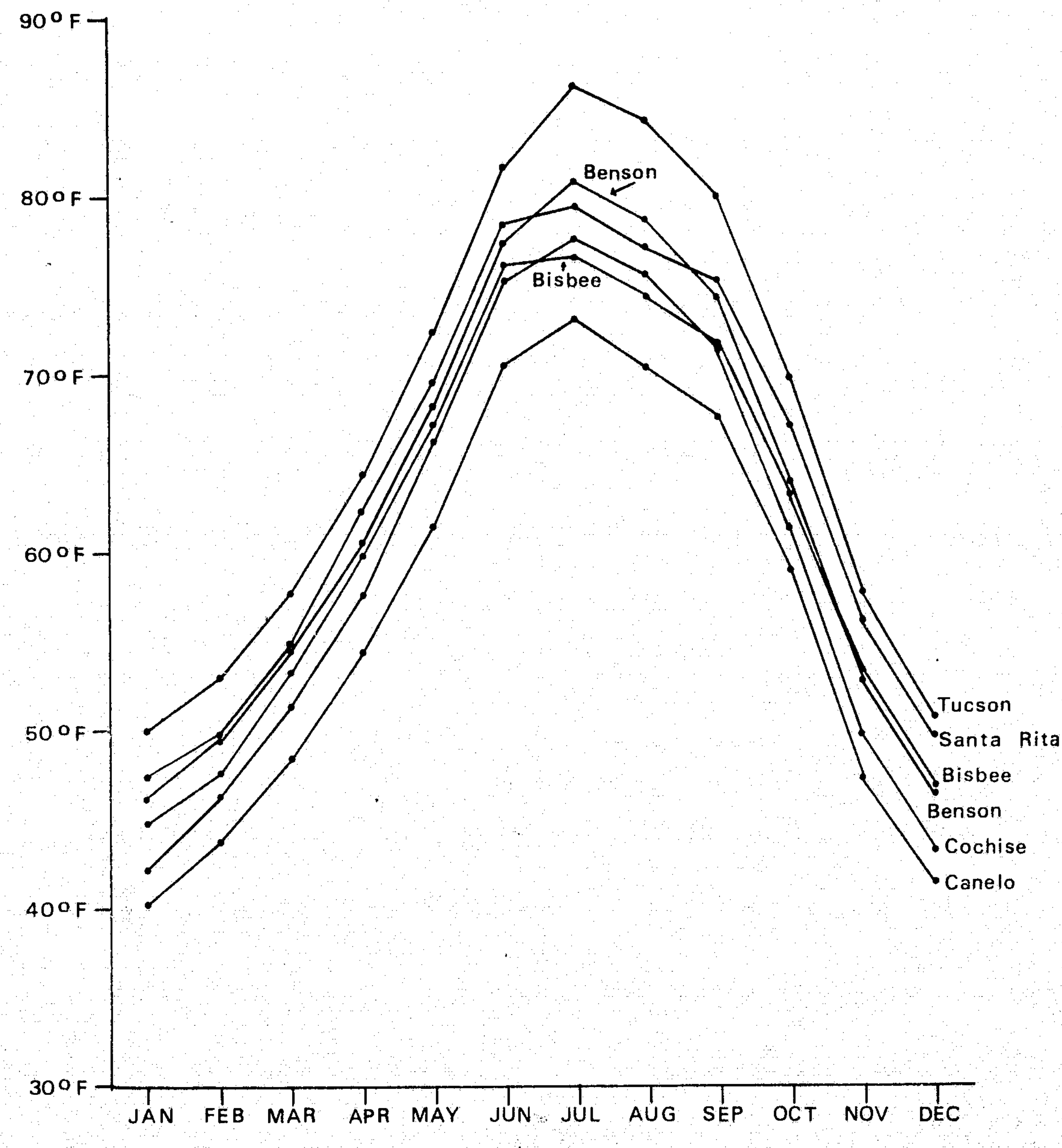
	Benson	Bisbee	Canelo	Cochise	S.R. Rng.*	Tucson
Elevation	3575'	5440'	4985'	4180'	4300'	2430'
Mean annual temperature	62.8°F	61.4°F	45.5°F	59.9°F	63.9°F	67.3°F
Ave. annual max. temp.	80.4°F	74.0°F	74.0°F	76.3°F	75.8°F	82.9°F
Ave. annual m min. temp.	45.1°F	48.7°F	38.9°F	43.5°F	52.0°F	51.6°F
a/	(28.9°F)	(34.3°F)	(23.9°F)	(26.9°F)	(36.9°F)	(35.2°F)
b/	(96.6°F)	(90.0°F)	(90.3°F)	(93.6°F)	(92.2°F)	(99.6°F)

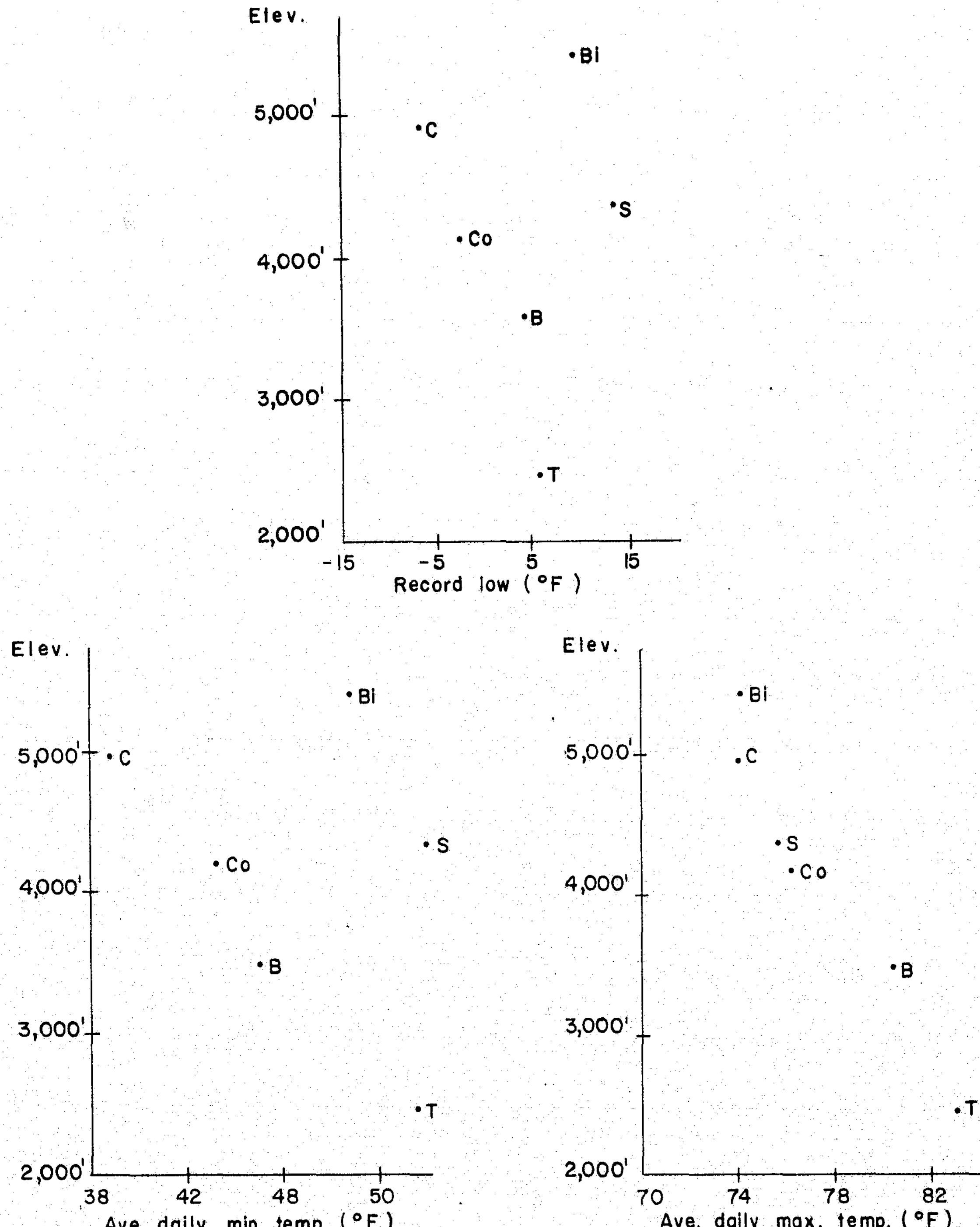
*S.R. Rng. = Santa Rita Range Experiment Station

a/ (lowest mean monthly minima in parentheses) January

b/ (highest mean monthly maxima in parentheses) June (Tucson is July)

Figure 2. Temperature data for six selected climate stations in the study area vicinity.


90° F
80° F
70° F
60° F
50° F
40° F
30° F
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Benson
Bisbee
Tucson
Santa Rita
Bisbee
Benson
Cochise
Canelo



B - Benson Bi - Bisbee C - Canelo Co - Cochise
S - Santa Rita Range Exp. Sta. T - Tucson

Figure 3. Selected climatic data for six selected stations in the study area vicinity.

and subfreezing temperatures. Cold air drainage is best developed with low humidity, clear skies, and long winter nights. Rapid radiative cooling results. The cold air being dense, stays near the surface and also drains downslope.

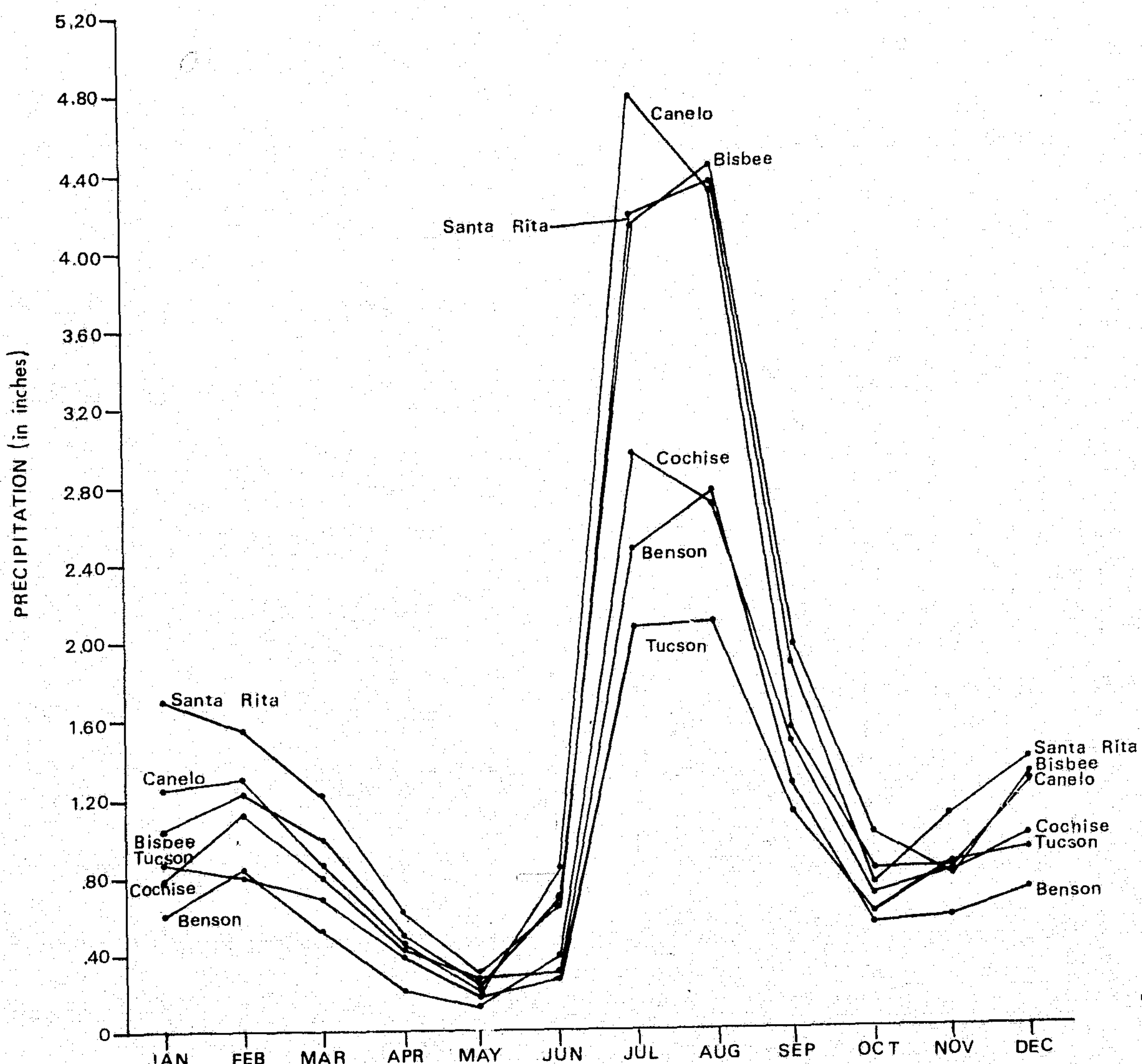
Precipitation is here discussed with relation to its amount, spatial distribution, seasonality, annual variation, and causal relations. Precipitation is generally lowest in the low elevations of the northwest (Tucson has 10.91" annually) and highest in the higher elevations of the southeast (Bisbee has 18.44" annually, although both Canelo and the Santa Rita Range Experiment Station, located at slightly lower elevations than Bisbee, have slightly greater annual amounts). Figure 4 illustrates the precipitation pattern of the six climate stations being discussed.

There exists a biseasonal distribution in the annual precipitation regime of climate stations within the study area. The principal peak occurs in the middle to late summer, while a lesser but still pronounced peak occurs in winter. The summer rain occurs usually as mid to late afternoon thundershowers, small in areal extent (one or two miles across) and of short duration. These rains are generally associated with the warm moist unstable air which circulates about the Bermuda high emanating from the Gulf of Mexico. Orographic lifting typically increases the amount. The winter rains are typically lighter in intensity, of longer duration, and generally

	Benson	Bisbee	Canelo	Cochise	S.R. Rng.*	Tucson
Mean annual precipitation	11.09"	18.44"	18.49"	13.35"	19.57"	10.91"

*S. R. Rng. = Santa Rita Range Experiment Station

Figure 4. Precipitation data for six selected climate stations in the study area vicinity.



PRECIPITATION (in inches)
5.20
4.80
4.40
4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
.80
.40
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Canelo
Bisbee
Santa Rita
Cochise
Benson
Tucson
Santa Rita
Canelo
Bisbee
Tucson
Cochise
Benson
Santa Rita
Bisbee
Canelo
Cochise
Tucson
Benson

cover a much wider area. The main cause of the winter precipitation is frontal. It generally comes from the cyclonic systems which are brought over southeastern Arizona by the westerlies. As one might expect, the greatest percentage of summer rainfall in the study area occurs in the southeastern portion of the study area. That portion is closest to the summer air mass source: the Gulf of Mexico. Figure 5 (taken from Hastings and Turner, 1965, p. 14) illustrates the percentage of precipitation falling in the six hottest months (May-October). Note that for the six stations studied, these percentages run from 58% to 68%. Many other stations within the study area report percentage of annual precipitation falling in the six hottest months over 70%. A more striking figure is the percentage of annual precipitation falling during the three wettest summer months. For the six stations studied, the percentages vary from 49% to 59%, only a slight reduction from the six month figure. This would seem to indicate that the driest times of the year occur just before and just after the summer rainy season. While annual precipitation in arid and semiarid regions is noted for being quite variable, the season of greatest variability in the study area is the winter and not the summer. In Tucson, the coefficient of variation is 40% during the summer but rises to 54% during the winter.

While precipitation in desert areas is often thought of as being extremely intense on occasion, with very high amounts during a

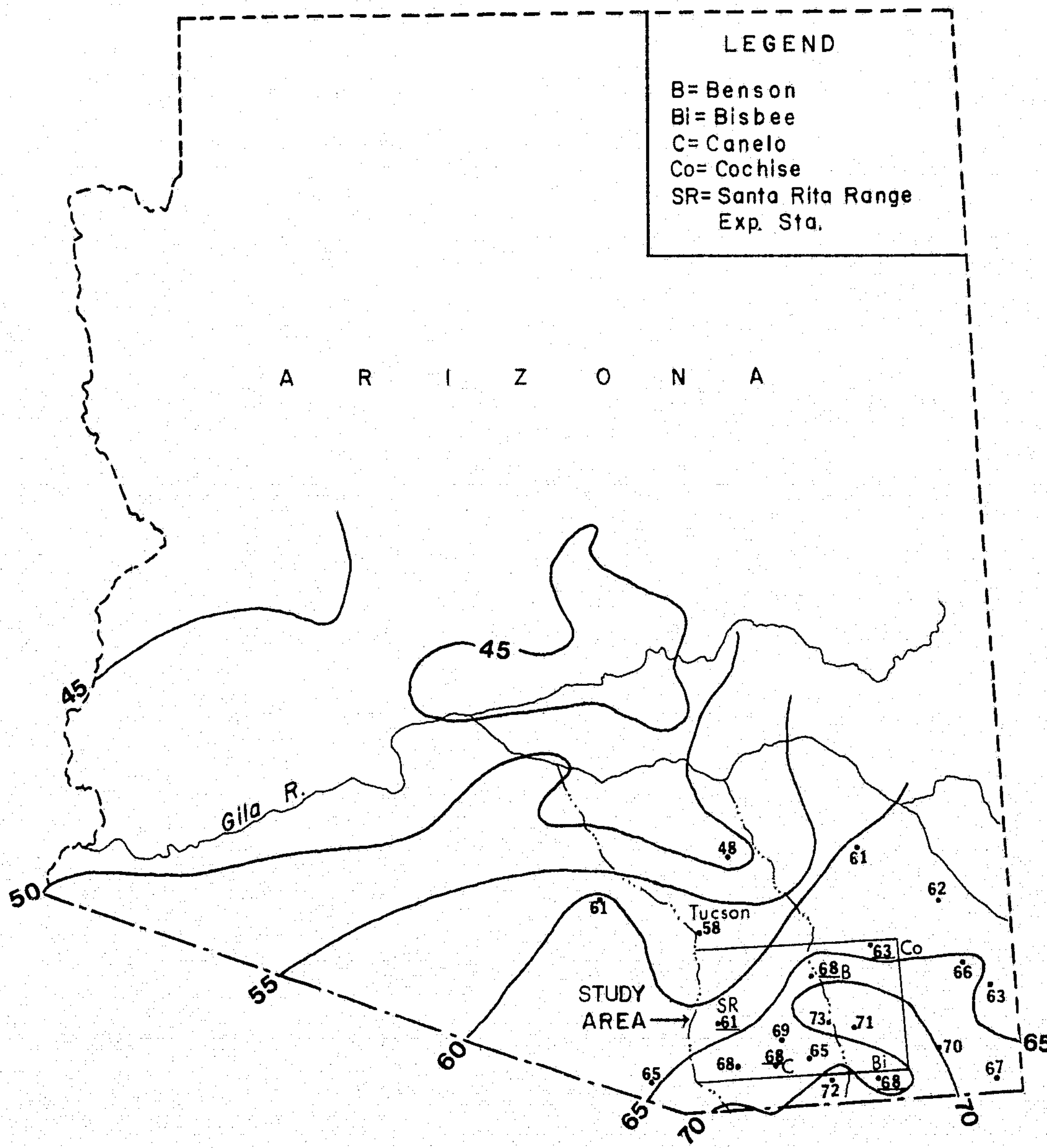


Figure 5. Percentage of precipitation falling in the six hottest months in southern Arizona.

twenty-four hour period once every several years, maximum twenty-four hour rainfall totals are not very great. For the entire state of Arizona, the maximum twenty-four hour total is less than six inches. Within the study area, Bisbee received 4.25" on July 22, 1910 between 4 p.m. and 5:10 p.m.

The Sonoran Desert has a unique and characteristic climate and microclimate that sets it apart from other deserts. Its plant life reflects these climatic characteristics as faithfully as the generally xeric nature of the desert vegetation reflects general aridity. While the general nature of the climate of the study area has been described, other factors need to be discussed in order to understand the type and distribution of the vegetation of the area. The steepness of a slope, the orientation of the plane on which it lies with respect to the sun, the reflectivity, or albedo, of the surface: these can modify considerably the small-scale climates over an area that has one homogeneous "temperature" when measured a few feet above the ground. This multitude of microclimates, in turn, results in a multitude of plant communities (Hastings and Turner, 1965; p. 7).

Landforms and Geology

The general topographic character of the study area is one of short, narrow, isolated mountain ranges ("island mountains")

scattered over extensive basins or bolsons consisting of bajadas, valley fill, and occasional lacustrine deposits. With the exception of the northeast corner of the study area where a portion of the Sulphur Springs Valley drains into Willcox Playa, drainage is external. Figure 6 illustrates on an ERTS-1 photograph some physiographic features of the study area. Figure 7 illustrates the geology of the study area. Numerous mountain systems occur within the study area. The Tanque Verde Mountains barely extend into the extreme northwest portion of the study area. The Rincon Mountains in the extreme north central portion of the study area rise over 4,000 feet above the surrounding plains to a maximum elevation of 8,400 feet. The Santa Rita Mountains dominate the western half of the study area. They rise, locally, over 5,000 feet above the surrounding plains with the highest point, Mt. Wrightson, reaching an elevation of 9,453 feet. The range is approximately twenty-five miles long and between five and ten miles in width. It trends approximately north to south. The Empire Mountains lie between the Santa Rita Mountains and the Rincon Mountains. They are a minor mountain system within the study area with a maximum relief of 1,000 feet and attaining a maximum elevation of only 5,400 feet. They are approximately eight miles in length, four miles in width, and trend northeast to southwest. The Canelo Hills in the southern portion of the study area are a low mountain system with a maximum elevation of 6,300 feet and maximum relief of about

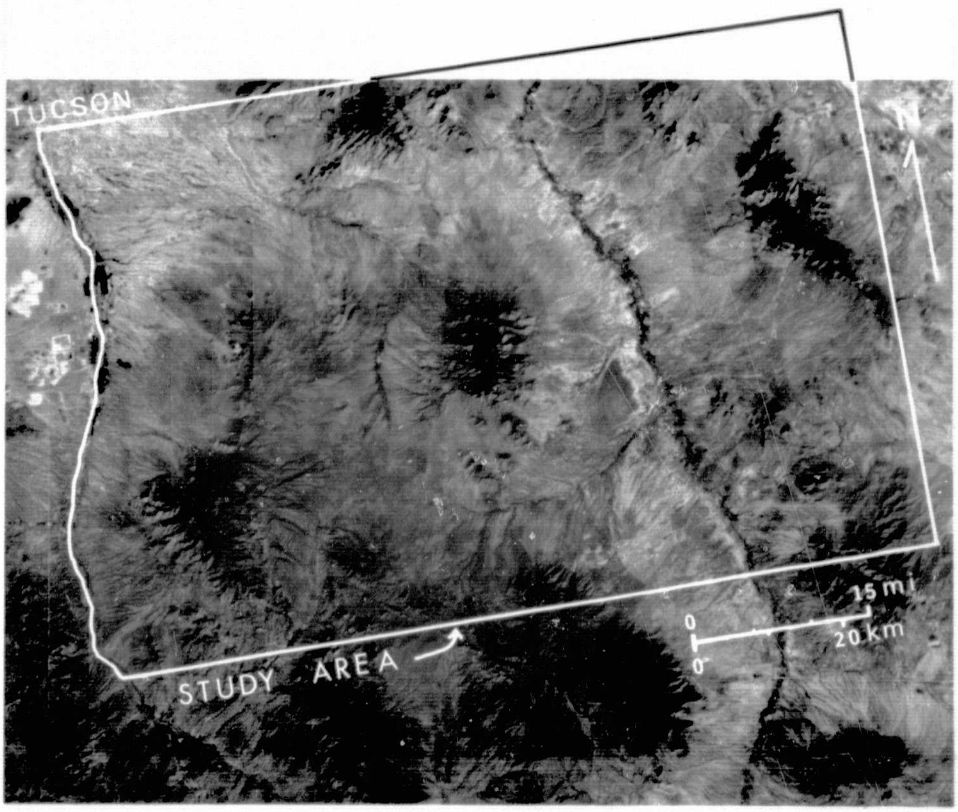


Figure 6. An Earth Resources Technology Satellite (ERTS-1) photo of the study area. (Frame 1102 - 17280 -5, 2 November, 1972. National Aeronautics and Space Administration - NASA).

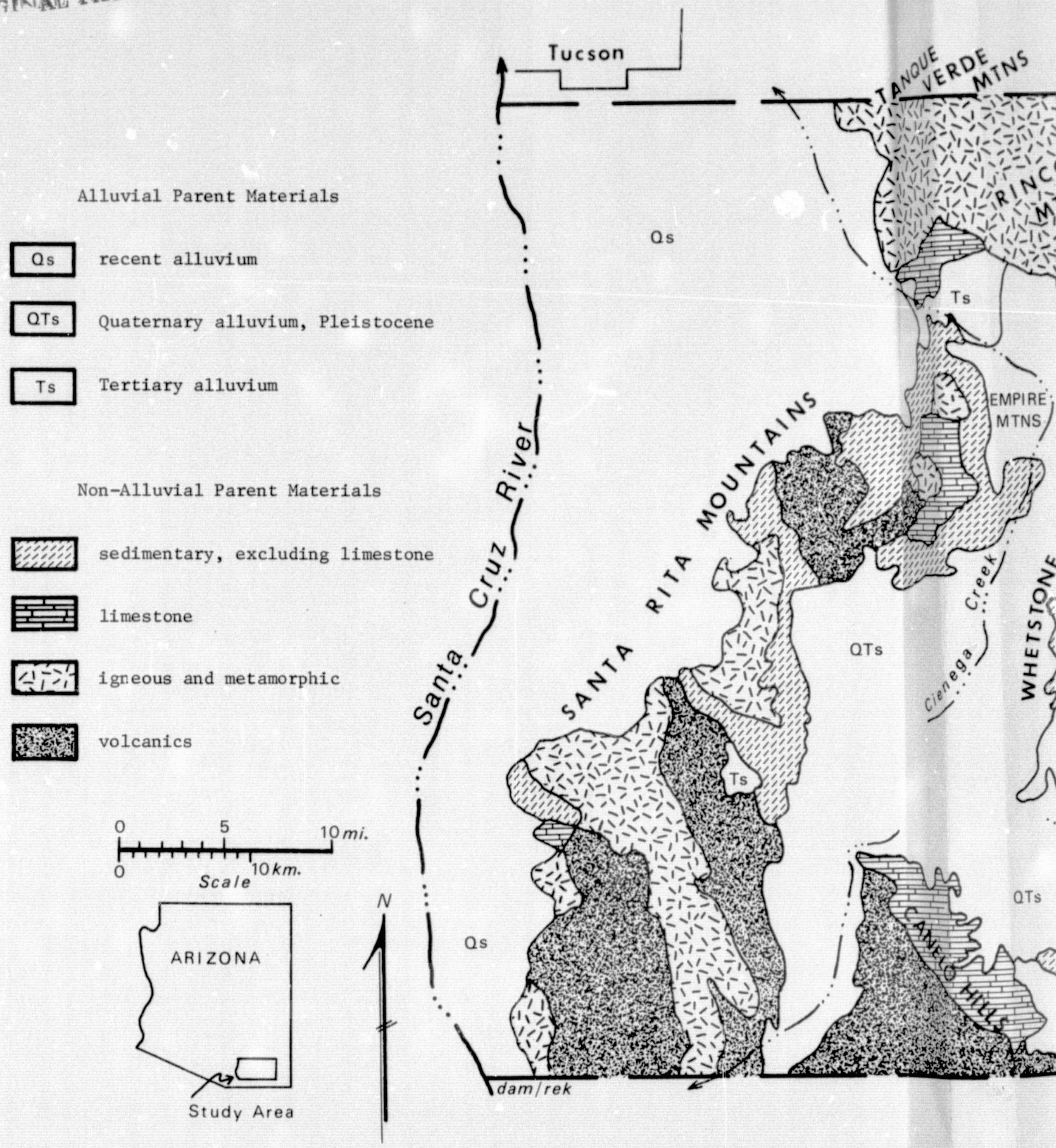
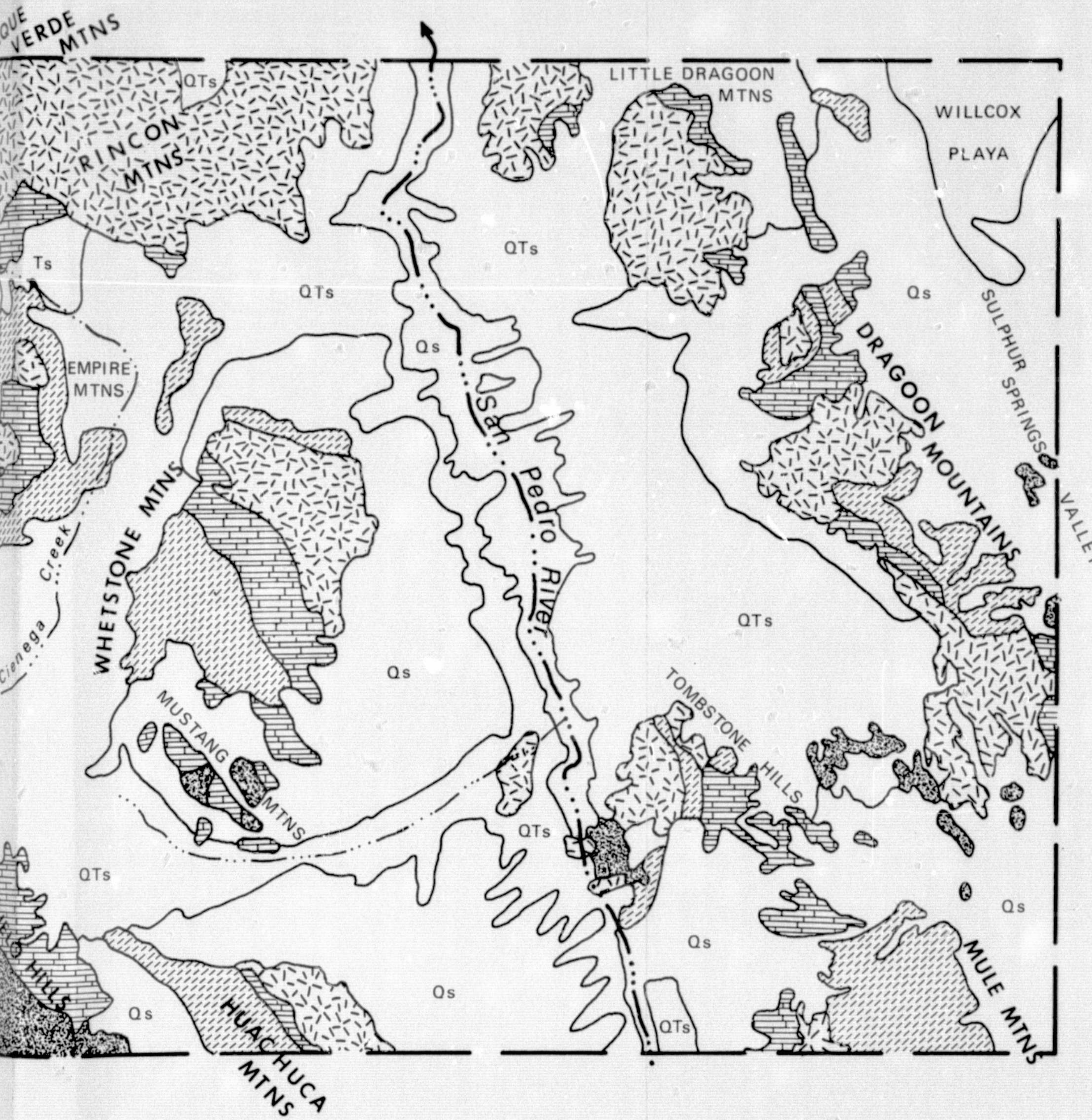


Figure 7. Geology of the study area.



FOLDOUT FRAME

1,000 feet. They trend northwest to southeast and are approximately twenty-two miles in length and five miles in width. Adjacent to the Canelo Hills on the east lie the impressive Huachuca Mountains. As Figure 6 illustrates, they lie only partially within the study area. While they are only about twenty miles long and seven miles wide, they rise nearly 5,000 feet above the surrounding plains that lie to the north and east. They are more massive than the Santa Rita Mountains. The Huachuca Mountains trend northwest to southeast and are parallel to the Canelo Hills. North of the Huachuca Mountains lie the Mustang and the Whetstone mountains. Both of these systems lie in the center of the study area. The Mustang Mountains are little more than hills as they rise less than 1,000 feet above the surrounding plains. They consist of a number of steep sided hills two to three miles long and a mile or so wide. The Whetstone Mountains to the north are an extremely rugged system eight miles wide and twelve miles long. Although they rise less than 2,000 feet above the surrounding plains, they consist of cliffs and steep slopes. Near the eastern border of the study area, the Dragoon and Little Dragoon mountains dominate the landscape. Those two systems are separated by a plain about three miles wide. Combined, they extend for approximately thirty-three miles trending northwest to southeast. The Little Dragoon Mountains rise to approximately 6,700 feet. They consist largely of low-relief rugged hills. The Dragoon Mountains

are a much more impressive system twenty-two miles long and seven miles wide, rising to elevations above 7,500 feet. The northern Dragoon Mountains consist of extremely rugged steep-sided mountains with relief in excess of 2,500 feet. The southern half consists essentially of a single ridge only a mile or two wide rising 2,000 feet above the surrounding plains. Southwest of the Dragoon Mountains lie the Tombstone Hills - a fairly extensive set of isolated hills occurring within an approximately sixty square mile area. Most of the hills rise considerably less than 1,000 feet above the surrounding plains. In the extreme southeast corner of the study area lie the Mule Mountains, a rugged series of mountains with difficult access. Within the study area they rise some 1,500 feet above the surrounding plains.

Four major valleys or basins occur within the study area. The Santa Cruz River drains a large basin west of the Santa Rita Mountains. The Santa Cruz River heads in the San Rafael Valley in the extreme south central part of the study area (see figure 6). It flows south into Mexico, then turns toward the west and north and flows back into Arizona. It forms the western edge of the study area. The Santa Cruz Valley, within the study area, is approximately ten miles in width west of the southern Santa Rita Mountains and widens to twenty-five miles east of Tucson. Except for the southwest corner of the study area, the Santa Cruz Valley is either

smooth or slightly dissected. Slope angles are generally low, 1% to 4%. Elevations range from 4,000 feet in the southwest to 2,600 feet in the extreme northwest, near Tucson. Trending nearly north to south in the central portion of the study area is the San Pedro River Valley. The valley is nearly fifty miles long within the study area and is as much as forty miles wide. It is the largest single physical feature within the study area, as Figure 6 illustrates. Much of the east side of the valley is moderately dissected with local relief of twenty to fifty feet. The west side of the valley is only slightly dissected. Elevations range from 5,000 feet at the base of the mountains to approximately 3,300 feet where the San Pedro River leaves the study area east of the Rincon Mountains. Between the San Pedro and the Santa Cruz valleys lies a fairly small high (elevation) basin sometimes referred to as the Empire Valley (Melton, 1965). Most of the valley lies at elevations of approximately 5,000 feet. The Empire Valley (locally known as a "valley", is actually a structural lowland) serves as the headwaters of three important drainage systems: Cienega Creek, which flows to the north between the Whetstone and the Empire mountains, and then west, ultimately joining the Santa Cruz River; Sonoita Creek, which flows to the southwest between the Canelo Hills and the Santa Rita Mountains, ultimately joining the Santa Cruz River near Nogales; and the Babocomari River, which flows eastward between the

Whetstone and the Huachuca mountains ultimately flowing into the San Pedro River near Tombstone. The Empire Valley consists of gently to moderately rolling terrain and some highly dissected terrain. The latter is located between the Whetstone and the Empire mountains. A fourth large basin contains the Sulphur Springs Valley. It has only limited extent within the study area and is located east of the Dragoon and Mule mountains. The Sulphur Springs Valley reaches a maximum elevation of 5,000 feet along the flanks of the mountains and a low of approximately 4,100 feet in Willcox Playa. The portion of the Sulphur Springs Valley draining into Willcox Playa is the only sizeable area of internal drainage within the study area. The slopes of the valley are quite smooth and gentle, typically being less than 2%. To the south of Willcox Playa, between the Mule Mountains and the Chiricahua Mountains to the east, the Sulphur Springs Valley drains into Whitewater Draw and flows south.

While the rock formations having surficial expression within the study area range in age from Pre-Cambrian to Recent, the current topography is primarily an expression of Tertiary and Recent geologic activity.

The Laramide orogeny extending from late-Cretaceous well into the Tertiary produced a considerable quantity of material as well as deforming the existing rocks. Later, the Basin and Range orogeny, accompanied by considerable compression as well as by

complex folding and faulting, produced the structure that is so evident in the present landscape. The folding and thrusting trended northeastward - the trend of most of the mountain ranges within the study area. The Basin and Range orogeny occurred from late Miocene into the Pliocene epoch. The Basin and Ranges, for the most part represent fault blocks of complex internal structure which were elevated in reference to adjacent, relatively depressed basins (Wilson, 1962). Most of the ranges within the study area are bounded by normal faults with thrust faulting evident in others. Concurrent with and following the Basin and Range orogeny was the filling of the basins. While this filling continues to the present, most of the activity took place in the Pliocene and the Pleistocene.

The oldest rock units in the study area are Pre-Cambrian gneisses and schists. Gneiss and granite-gneiss are the principal components of the Rincon and southern Tanque Verde mountains. Much of the northern Whetstone and eastern Huachuca mountains are composed of Pre-Cambrian granite. The Pinal schist is exposed in the southeast Rincon Mountains and in isolated patches in the Dragoon, Little Dragoon, and Whetstone mountains, and in Tombstone Canyon in the Mule Mountains.

The Paleozoic era has moderate surface expression within the study area. Most of the units present are sedimentary. The Bolsa Quartzite is considered to be the most resistant unit within the study

area (Gilluly, 1956). It constitutes the western flank of the southern Dragoon Mountains. Paleozoic sedimentary units in the study area are predominantly limestone. The Escabrosa limestone and the Naco group are the chief units of the Paleozoic era within the study area. They crop out in the central Empire Mountains, in the southwest Rincon Mountains, sparingly in the Santa Rita Mountains, over much of the central Whetstone Mountains, and central Huachuca Mountains. Paleozoic limestone comprises nearly all of the northern Canelo Hills, much of the Mustang Mountains, the western Mule Mountains, the southeast Tombstone Hills, and the northern Dragoon Mountains.

The Mesozoic era is characterized by extrusive and intrusive igneous rocks and considerable sedimentary rocks. Nearly all of the central Canelo Hills, which contain the principal ridges of that system, consist of Mesozoic andesite. Other Mesozoic extrusive volcanic outcrops occur in the Santa Rita Mountains. Mesozoic granite crops out on either side of Tombstone Canyon in the northern Mule Mountains. The Gleeson quartz monzonite is the principal constituent of the southern tip of the Dragoon Mountains. The Bisbee group constitutes the principal sedimentary formation of the Mesozoic era within the study area. Those Cretaceous sediments occur over extensive areas within the study area. Most of the outer Empire Mountains, the south half of the Whetstone Mountains, and the western

half of the Huachuca Mountains consist of the Bisbee group sediments. Nearly all of the northeast two-thirds of the Mule Mountains consist of Bisbee group Cretaceous sediments. The Bisbee group also makes up nearly all of the eastern half of the southern Dragoon Mountains, within the northern Dragoon Mountains, and within the Tombstone Hills.

Rock units of the Cenozoic era consist of extensive outcrops of intrusive and extrusive igneous rocks of the Tertiary (primarily a product of the Laramide orogeny), as well as extensive unconsolidated alluvial deposits of the Quaternary. Granitic rocks associated with the Laramide orogeny crop out extensively within the Santa Rita Mountains, in a pediment west of the Rincon Mountains, and in the eastern Rincon Mountains. Laramide volcanics within the study area include an extensive area of andesite in the southwest part of the study area, and numerous rhyolitic and andesitic hills southwest and east of the Dragoon Mountains.

Late Tertiary sedimentary rocks occur in several places in the study area. The major locality is between the Rincon Mountains and the Empire Mountains. An isolated valley in the eastern Santa Rita Mountains and a small patch near Fort Huachuca constitutes most of the remainder. These late-Tertiary sediments probably consist of Gila conglomerate. The Gila conglomerate is considered to date from one of the first episodes of alluvial deposition correlative

with the Basin and Range orogeny. Supposedly, Gila conglomerate underlies most of the more recent alluvial deposits in the study area (Tuan, 1962).

Quaternary surface materials in the study area include some very small outcrops of basalt in the Tombstone Hills as well as extensive unconsolidated alluvial deposits. Early Quaternary alluvium fills the Empire Valley basin. Extensive early Quaternary alluvium crops out over most of the San Pedro Valley north of Benson and between the San Pedro River and the Dragoon Mountains. Late-Quaternary alluvium covers most of the west San Pedro Valley south of Benson, the Sulphur Springs Valley, and all of the Santa Cruz Valley within the study area. Recent lacustrine sediments are at the surface over much of the Willcox Playa region.

The topography of the study area is extremely varied. Maximum local relief is over 5,000 feet within a horizontal distance of less than two miles. In other areas, the topography is essentially level and smooth with local relief less than one foot. General geomorphic descriptions of the study area region usually distinguish four broad geomorphic surfaces: mountains, old alluvial surfaces, young alluvial fans, and river floodplains (for example, Hendricks and Havens, 1970). I would add pediment surfaces to that list.

While some early authors considered any gently sloping surfaces extending away from a mountain mass to be a pediment

(Bryan, 1926; Gilluly, 1956), more recent studies (for example Tuan, 1959, 1962) restrict the definition to include only those gently sloping planar surfaces that have been formed by erosion and are composed of bedrock.

According to Cooley (1965, personal communication February, 1972), pediments occur in the following places: in the valley between the Tanque Verde and Rincon mountains, the western fringe of the northern Santa Rita Mountains, the eastern fringe of the Empire Mountains, a small area southwest of the Whetstone Mountains, an extensive area extending from the Huachuca Mountains toward the Mustang Mountains, an extensive area in the Little Dragoon Mountains, a small area within the Tombstone Hills, a small area near Stronghold Canyon in the western Dragoon Mountains, and fairly large areas east and south of the Dragoon Mountains. Cooley, however, considers the surfaces to be pediments even if they are overlain by 100 feet or more of alluvium (personal communication, February, 1972). Tuan restricts pediments to those which are near or at the surface. Tuan suggests that pedimentation is an indication of the degree of degradation of the adjoining mountain mass. The relatively small size of the pediments within the study area would indicate that the period of uplift which formed the adjoining mountains was relatively recent. According to Tuan (1959), pediments represent exhumed suballuvial benches. That is, they were created

when stream erosion denuded a mountain front producing an undulatory surface buried in alluvium. Later, stream-flood runoff removed the alluvial cover and exposed the pediment.

Tuan recognized a narrow bench-like pediment occurring along the northeast tip of the Huachuca Mountains. In the Dragoon Mountains, Tuan recognized the same three pediments that were later recognized by Cooley. The pediment located immediately south of Stronghold Canyon has an area of about four square miles. The surface of that pediment is quite smooth save for the occasional granitic tor. Another granitic pediment with an area of about twenty-two square miles and an undulating topography occurs south of the Dragoon Mountains. The third pediment has an area of about eleven square miles and has been developed from sedimentary rocks. It is located off the eastern flank of the southern Dragoon Mountains. Another major pediment recognized by Tuan (1959) is located within and immediately to the south of Little Dragoon Mountains, occupying the area known as Texas Canyon - a popular site for Hollywood western movies. The pediment is approximately ten square miles in extent and is developed on granite. The pediment has a classic assemblage of tors, boulders, and other outliers.

The basin fill between the mountains is recognized as having a number of erosional surfaces. The oldest, or Gila Conglomerate of Pliocene age, has been mentioned earlier. The erosional and

depositional surfaces are a result of large-scale pulses of faulting, epeirogenic upwarping, and subsidence (Cooley, 1968). Stability between those differential movements allowed the development of broad erosional surfaces and concomitant depositional surfaces on the basin fill. In the San Pedro Valley, within the study area, at least three distinct erosional surfaces are present (Martin, 1963). Bryan (1926) named two of those surfaces "pediments" - they are, in fact, bajadas. Those two surfaces are the Tombstone and the Whetstone. The Tombstone surface (the older of the two) covers most of the basin fill south of the Tombstone Hills while the Whetstone surface covers most of the basin fill north of the Tombstone Hills. The youngest surface, the Aravaipa, is a post-Pleistocene surface correlative to the present San Pedro River floodplain. Presumably, the surface of the Sulphur Springs Valley, being a recent depositional feature, is closer in age to the Aravaipa Surface than to the preceding surfaces. The surface of the Empire Valley basin is probably early Pleistocene - possibly correlative with the Tombstone Surface. The surface of the Santa Cruz Valley is varied in age but indications are that it is of mid-Pleistocene and later in age.

Soils

Nearly all investigators of physical environmental interrelationships have found that edaphic factors comprise an integral

role in the environmental complex. In this study, soil properties are not employed to assess relationships between terrain variables and vegetation. However, it is partly through soils that the importance of terrain variables, as they are related to vegetation, is manifest.

Soils developed on parent materials in rugged terrain are often thin and poorly developed because they have not had sufficient time to develop; weathered materials erode away faster than they can accumulate. Jahn (cited in Bunting, 1967) suggested that this question of equilibrium is determined by 1) the climatically controlled alteration and crumbling of rocks (weathering), and 2) denudation (eroding forces). The weathering mantle deepens progressively unless the denuding forces remove it. In steep rugged terrain, denudation prevails.

Parent materials obviously supply the mineral constituents to the soil and are the inorganic base of the solum. Different types of parent materials under similar geomorphic conditions usually undergo weathering and erosion at different rates and thus tend to produce soils with different chemical and physical properties.

The development of organic material within soils is generally minimized in arid environments. Semiarid grasslands, shrub-scrub lands, and woodlands tend to develop an organic content in the soil significant enough to darken the "A" horizon. Through its physical

characteristics, the soil definitely affects the overlying vegetation (and vice versa). Many species are restricted by soil depth; some species occur only on deep soils while others only on shallow rocky soils. Some species grow only on limestone, while others will not grow on limestone parent materials (calciphiles and calciphobes, respectively). Many soils within my study area have a highly indurated calcic or petrocalcic horizon a few inches below the surface. This horizon, in this case a "pan", severely restricts downward movement or penetration by roots. This pan also may effect a perched water table, which, of course, would affect plant growth.

Carbonate pans, are found in my study area. Gypsic and salic horizons are other types of pans which may exist in semiarid regions (although they are usually better developed in more arid environments). Salic horizons exist in Willcox Playa and vicinity (Richardson, personal communication; February, 1972).

In semiarid regions, an argillic horizon may coincide with the calcic horizon or may overlie or underlie it (Gile and Grossman, 1968). This fact is significant for two reasons. The first is that argids, a suborder of aridisols, are quite common in the study area and are dependent upon the presence of an argillic horizon; calcic horizons are also quite common within the study area. The second significant reason lies in the mode of formation of the horizons.

Calcic horizons are the product of an arid or semiarid environment. Argillic horizons (these are horizons having a significant increase in clay content in the "B" horizons), on the other hand, are usually the product of humid or subhumid conditions. Downward percolation of water and considerable lengths of time are associated with their formation. The implication of the presence of an argillic horizon in a semiarid environment might be a prior more humid climate. Research in other fields in southern Arizona tends to support this implication (Hastings and Turner, 1965).

Hendricks and Havens (1970) assert that the soils in southeast Arizona can be conveniently grouped in terms of the region's geomorphology. In its general soil classification, the Soil Conservation Service used parent material, topography, time, and climate as separating criteria (Richardson, 1971; and personal communication; February, 1972). The Soil Conservation Service has yet to produce an up-to-date soils map of the region containing the study area, utilizing morphological and genetic information as mapping criteria. The first step toward achieving that end, however, has been accomplished by the Soil Conservation Service. That step is the identification of the major soil series of the area.

Hendricks and Havens (1970) recognized four general geomorphic surfaces in southeast Arizona as being significant in soil genesis: mountains, old alluvial surfaces, young alluvial fans, and river

floodplains. With one or two exceptions, and with some modification, those surfaces represent the general geomorphic aspect of my study area.

The soils of the mountains are mostly shallow and rocky, being derived from differing parent materials. The degree of profile development (and subsequently place in a classification) is variable depending upon the stability of the erosional surface and the parent material (Hendricks and Havens, 1970). Hendricks and Havens recognized two general groups of soils on the basis of parent materials: soils formed on granitic and schistose rocks, and soils formed on volcanic rocks.

Granitic and related rocks tend to weather into fine gravel and sand which is readily and rapidly removed by erosion, particularly on the steeper slopes. These soils, therefore, are shallow and poorly developed. Orthent is a typical suborder of soils developed from those parent materials. Soils developed from volcanic rocks weather from the outside inward with very little intermediate regolith. The weathered products do not tend to be readily removable and frequently a deep profile with a petrocalcic horizon is present. This type of situation is typically reflected by soils classified in the argid suborder. A third type of parent material, limestone, had only a small coverage in the Hendricks and Havens study. Limestone soils, therefore, have a tendency to be mollisols. Most

mollisols in the study area are ustolls.

Old alluvial surfaces include old dissected bajadas and other surfaces which no longer receive alluvium. The surfaces have been exposed to weathering, and hence soil formation, for a long time. As such, soils developing upon those types of surfaces tend to have a high degree of profile development. Soils formed on old alluvial surfaces are generally classed in one of two groups: those having an argillic horizon, and those having a calcic or petrocalcic horizon. Argids are those suborders of aridisols having argillic horizons while soils with calcic or petrocalcic horizons fall into the orthid suborder.

Young alluvial fan surfaces include those surfaces upon which alluvial deposition is taking place. The parent material of the fan may be from the surrounding mountains or it may be from older alluvial surfaces. Buried soil profiles frequently occur under these soils. Because of their immaturity, these soils usually are entisols - fluvents or orthents, although mollisols (the order with a dark well-developed "A" horizon) can occur on fairly young alluvial surfaces.

Floodplain soils are also composed of recent alluvium and are usually nearly level. Some floodplain soils are mollisols (ustolls), especially those formed under cienegas (meadow-like swamps having a high water table). Other floodplain soils are quite immature with

little diagnostic soil profile development or characteristics and are thus classed as entisols (usually fluvents).

According to the Soil Conservation Service classification (SCS summary of interpretations of soil series, personal communication with Richardson, February, 1972), more than 52 series have been identified as occurring within my study area. These series come from five orders and eight suborders of the Seventh Approximation of Soil Classification (SCS, 1970). Entisols (fluvents and orthents) represent immature soils without much profile development and are frequently found in areas of recent alluvial deposition. Six series in my study area are recognized as belonging to this order.

Eighteen series come from the mollisol order which has only one suborder, ustoll, occurring within the study area. Mollisols are characterized by having a dark thick "A" horizon (a mollic epipedon is diagnostic); most mollisols occur in grasslands.

Five series were recognized as coming from the order alfisol, which has one suborder, ustalf, occurring in the study area. These soils occur at higher elevations of the study area.

One series was recognized within the vertisol order (ustert suborder). These soils are clayey and have the characteristic of cracking, shrinking, and swelling.

The final order, aridisols, has twenty-two series recognized as occurring within the study area. Two suborders, orthids and

argids, occur. Aridisols are well-developed soils occurring in arid and semiarid regions. They usually have light colored "A" horizons and "B" horizons with a clay accumulation. Calcic, petrocalcic, or argillic horizons are nearly always present in those aridisols occurring in the study area. Where they occur in alluvial parent materials, aridisols represent soils formed on older geomorphic surfaces (probably early to mid-Pleistocene).

Vegetation and Flora

There are five excellent references on the flora of Arizona including the study area. Kearney and Peebles (1964) made an exhaustive study of the Arizona flora. Their work is probably the basic taxonomic reference on the subject and it provided great assistance to this research in the identification of species. Benson and Darrow (1954) prepared an invaluable guide on the trees and shrubs of the southwest deserts. In it, they discussed the majority of the trees and shrubs found within the study area. The work consists of excellent descriptions and includes distributional data for the species. Benson (1969) also published an easy-to-follow book on the cacti of Arizona. His work provides descriptions and distributional data for the cacti. Shreve and Wiggins (1964) made a complete study of the vegetation and flora of the Sonoran Desert. Their book is a good supplement to Kearney and Peebles' Flora of

Arizona (1964). Hastings, Turner, and Warren (1972) prepared An Atlas of Some Plant Distributions in the Sonoran Desert. Their study area within Arizona is essentially all of southern Arizona, hence it includes the study area of this research. They accurately displayed the distribution of 238 woody and succulent species on separate maps. Most of the important woody and succulent species occurring within the study area are included.

No studies have adequately described the vegetation types of the entire study area at a scale compatible with this research. A few researchers have investigated small areas within the study area, while others have indulged in broad generalizations in which the study area would be but a small part. General vegetation studies which would include the study area adequately describe the broad vegetation types of the study area.

Even a cursory examination of the vegetation of the study area would be incomplete without some mention of the changing pattern of that vegetation over time.

Much of the early work on forage production on Arizona rangelands (see, for example, Darrow, 1944; Humphrey, 1960) emphasized the deterioration of the grasslands of southern Arizona and the nearly simultaneous "invasion" of those grasslands by "noxious invaders of the grasslands" (Lowe, 1964). As early as 1910, concern was expressed for the changing vegetation (Griffiths, 1910).

While palynological evidence clearly indicates a changing climate and a concomitant change in vegetation over the last 10,000 years (Martin, 1963), the attempt here is to summarize the explanations given for recent, or "post-white-man" (Morrison, 1972; also Hastings and Turner, 1965) changes in vegetation.

In general, it can be said that the theories postulated to explain vegetation change in the study area region fall into the following broad categories: cattle (through overgrazing and seed dissemination), fire, climatic change, and rodents (through predator control).

Early observations on the Santa Rita Experimental Range (Griffiths, 1910; Thornber, 1909, 1910) noted a deterioration of the grassland and an increase in mesquite as due "not to heavy grazing ... but directly to the prevention of fires" (Griffiths, 1910). Prevention of fires continues to be a major reason given for the deterioration of the grassland. Humphrey (1953 and 1958) concluded that there has not been a major change in climate that would result in vegetation change. Humphrey suggested that cattle grazing, as an important mechanism in the dissemination of the seeds of shrubby plants, rodents, and the suppression of fires which once maintained the grasslands, could explain the change in vegetation. Therefore, he postulated, the shrub invasion of the grasslands is largely due to the reduction of range fires. Reynolds and Bohning (1956)

conducted an experiment on the effects of burning on vegetation and concluded that the suppression of fire can be considered a major reason for the deterioration of the grasslands.

Roger Morrison (1972) suggests that changing climate accompanied the heavy grazing of the late-nineteenth century. The heavy grazing resulted in a removal of the grass cover. The climatic change consisted of increased aridity as well as increased torrentiality of the precipitation; hence, arroyo-cutting and further deterioration of the range resulted.

Hastings (1959) discussed three categories of hypotheses as accounting for vegetation change. Overgrazing and effects of man on predators and prey constitute one category. Diastrophism constitutes another, and climatic change the third. Hastings tended toward favoring a "trigger-pull" hypothesis in which long-term trends favoring increased erosion were triggered by the heavy grazing pressure of the late-nineteenth century. Historical records indicate a close correlation between the livestock population and the onset of stream trenching.

A major work on vegetation change in southern Arizona is The Changing Mile (Hastings and Turner, 1965). The authors use early photographic records matched with recent photographs to document examples of vegetation change.

Hastings and Turner noted in the oak woodland a decrease in Quercus spp. and Dasylirion wheeleri, and increases in shrubs, Prosopis juliflora, Juniperus spp., and Nolina microcarpa. They drew the following conclusions for the oak woodland: 1) at all elevations below 4,500 feet, oaks have died faster than they have become established, 2) oak mortality is greatest at the lowest elevations of the oak woodland, 3) because of shrub invasion, the woodland is less open, 4) the Prosopis juliflora invasion antedates the oak decline, and 5) the current oak decline may be the most severe vegetation fluctuation in the last several thousand years (Hastings and Turner, 1965). They noted that woody species have increased dramatically in the desert grassland. Prosopis juliflora and Fouquieria splendens (ocotillo) have increased greatly throughout the grasslands of the study area. Acacia vernicosa, Flourencia cernua, Aloysia wrightii, and Mortonia scabrella have increased in the San Pedro grasslands. Acacia constricta, Salsola spp., Haplopappus tenuisectus, and Juniperus monosperma have increased in the Santa Rita region (roughly including the grasslands of the western half of the study area) grasslands. Changes in the desert life zone have not been as striking as on the desert grassland or oak woodland. Hastings and Turner noted that Encelia farinosa and Zinnia pumila have declined. Cereus giganteus (saguaro), while apparently unchanged on rocky slopes, has declined elsewhere.

Cercidium spp. (paloverde) as well as Prosopis juliflora appear to have increased in the upper part of their ranges while they have decreased in the lower part. Hence, it appears as if the desert zone is migrating upward.

Hastings and Turner carefully reviewed the various hypotheses on the causes of vegetation change in southern Arizona. They suggested that the effect of livestock has been an important factor in the vegetation change, most noticeably in the grasslands. It has not, however, been the principal agent of change. They showed that large-scale grazing during the 1820's and 1830's was not accompanied by vegetation or hydrologic change. The theory that settlement resulted in a suppression of predators, a resultant increase in rodent numbers, hence a strain on the vegetation is tenuous at best, according to Hastings and Turner. Their observations on the fire theory are most important. Discounting the fire theory, Hastings and Turner remarked (p. 287):

> ...In the one case burning must occur frequently enough to keep all mesquites suppressed; in the other, infrequently enough to permit some oaks to become established. There is no historical reason to suppose that the requisite frequency of burning in the two zones followed such a pattern ... How in terms of the fire suppression hypothesis, can one account for the recent invasion of the woodland by mesquite? It becomes necessary to postulate conditions in the past when fire, sweeping the one zone - the woodland - was at once able to eliminate all young mesquites, but to leave many young oaks for replacement purposes. There is no evidence that young oaks are more fire-resistant than young mesquites; even if they were, one

> has difficulty envisioning wild fires that everywhere were so nicely adjusted in temperature that they could perform this selective function over thousands of square miles without fail.
>
> If one starts with the initial assumption that the oak savanna, like the grassland, is fire-induced, there is no combination of circumstances that can explain the past existence of the two side by side in a brush-free condition. If, on the other hand, the savanna is not a fire-induced form, what used to keep it free of mesquite? In terms of the fire hypothesis it is possible to imagine an oak-mesquite woodland in the past, but not an oak woodland. Clearly factors other than fire suppression must be involved in the recent invasion of the oak zone by mesquite.
>
> From this argument one can only conclude that fire was not the primary mechanism that used to keep the desert grassland and the oak woodland free from shrubs. Coupled with the more direct historical and photographic evidence, the chain of inference supplies a tentative answer to the second question: there is no reason to suppose that fires used to sweep the desert grassland frequently or on a large scale.
>
> And on the basis of this answer one must reject the hypothesis that fire suppression has been a primary cause of the changes. At the same time one can readily grant the usefulness of fire as a tool in range management, and concede that fires, where they did occur in times past, were probably locally effective in keeping shrub establishment lower than it would otherwise have been.

According to Hastings and Turner, the hypothesis of climatic change has validity through indications of increasing "aridification". Apparently, vegetation was altered enough by 1890 to affect runoff and initiate arroyo-cutting. Supposedly, the warming and increased

aridity began about 1870. Hastings and Turner did not reject this hypothesis. They decided that a combination of overgrazing accompanied more or less contemporaneously by climatic stress resulted in the changes of vegetation.

Among the most basic divisions of the vegetation of the study area region is Shreve's "nine principal types of vegetation" discussed in Kearney and Peebles (1942 and 1964). Those types which would be found in the study area include the Western Xeric Evergreen Forest which consists of several evergreen species of Quercus, Pinus cembroides, and Juniperus deppeana. At higher elevations, though still within the study area, Pinus spp. are the dominant tree species. Smaller, associated species include Yucca spp., Agave spp., Nolina microcarpa, and Dasylirion wheeleri. Deciduous trees such as Populus fremontii, Juglans major, Platanus wrightii, and Fraxinus velutina are confined almost entirely to the banks of the streams.

Shreve mentions two types of "grassland": Grassland and Desert-Grassland Transition. The primary difference between the two lies in the fact that the Desert-Grassland Transition impinges upon the Arizona Succulent Desert. It has a larger admixture of cacti, Yucca spp., and yucca-like plants. Both types in the study area are characterized by numerous grass species (primarily Bouteloua spp. and Aristida spp.).

The Arizona Chaparral occurs only sparsely in the study area. It is characterized by sclerophyllous shrubs (shrubs having small, thick, hard, waxy, evergreen leaves). Quercus turbinella, Arctostaphylos spp., Cercocarpus breviflorus, and Ceanothus greggii are important species of the chaparral.

The Arizona Succulent Desert reaches its greatest development in southwest Arizona, although it does extend into the study area. It is characterized by numerous cacti including Cereus giganteus and Opuntia spp. (several species of cholla and prickly pear). An extremely abundant species in this type is Larrea tridentata. Cercidium spp., Fouquieria splendens, and Prosopis juliflora are very common components.

Humphrey (map, 1963; description, 1960) has identified four major divisions of vegetation which occur within my study area. These include Southern Desert Scrub, Grassland, Chaparral, and Juniper-Pinyon or Oak Woodland. The woodland type occurs at elevations ranging from 4,500 feet to 6,500 feet, and may be intermixed with Chaparral. Principal tree species include Juniperus deppeana, Quercus emoryi, Q. oblongifolia, Q. arizonica, Q. hypoleucoides, and Pinus cembroides. Other common species include Garrya wrightii, Ceanothus greggii, Cercocarpus breviflorus, and numerous grasses including several species of Bouteloua, Aristida, Eragrostis, and Andropogon. The Chaparral occurs at elevations

ranging from 4,000 feet to 5,000 feet in the mountain foothill zone, and is often difficult to distinguish from the Juniper-Oak Woodland because of similar appearance (Humphrey, 1960).

Humphrey used the term "Desert Grassland" rather than "Grassland" to indicate that type in the study area region. He recognized it as occurring between 3,000 feet and 5,000 feet with the best development on bajadas and outwash plains. It is bordered along its lower edge by the Southern-Desert Scrub type. Humphrey recognized vegetation change as an extremely important factor affecting southern Arizona landscape and noted that it was most pronounced in the grassland. He recognized Prosopis juliflora, Haplopappus tenuisectus, both types of Opuntia spp., and other shrubs and succulents as encroaching on the Desert Grassland. Bouteloua spp. were the most important grasses he recognized in the type. Other important grasses included Aristida spp., Eragrotis spp., Trichachne californica, Heteropogon contorta, and Leptochloa dubia. Among the woody "invaders" (in addition to those mentioned previously) are Calliandra eriopoda, Mimosa biuncifera, Fouquieria splendens, Agave schottii, and Yucca spp. Humphrey's Southern Desert Scrub comprises only the vegetation for the western portion of the study area (that portion dominated by Sonoran Desert influences as opposed to the Chihuahuan Desert influence in the eastern half of the study area). The dominant shrub recognized is Larrea tridentata.

Cercidium spp., Acacia greggii, and Prosopis juliflora are common shrubs. Among cacti, Cereus giganteus, both types of Opuntia spp., and Ferocactus wislizenii are most common. Fouquieria splendens is another common constituent of the type.

Nichol (1937) in his article on the "Natural Vegetation of Arizona", described three basic types of vegetation: Forests, Grasslands, and Desert. Under Forests he has included Pinyon-Juniper, Chaparral, and Oak Woodland as occurring within the study area. Essentially the same species given by Humphrey were used to comprise those types. "Desert Grassland" was the name given by Nichol to the grassland found occurring within the study area. In addition to Bouteloua spp., Nichol mentioned the importance of Hilaria belangeri, H. mutica, and Sporobolus wrightii. He also recognized Prosopis juliflora, Yucca elata, Opuntia spp. (cholla), and an occasional Quercus emoryi as non-grass species occurring within the "Desert Grassland". Under Desert, Nichol recognized the Creosotebush (Larrea tridentata) - Saltbush (Atriplex spp.) type, and the Paloverde (Cercidium spp.) - Bursage (Franseria dumosa) - Cacti type as occurring within the study area. The latter type occurs only in a small part of the study area in the foothills of the Tanque Verde Mountains. The type is characterized by Cercidium spp., Encelia farinosa, Aloysia wrightii, numerous other shrubs, Fouquieria splendens, and numerous cacti. Nichol has recognized

five subtypes of the Creosotebush - Saltbush type. The Creosotebush subtype occurs in nearly pure stands and is abundant in the northwest portion of the study area on the valley-fill southeast of Tucson. The Saltbush subtype occurs in saline-alkaline soils. The fringes of Willcox Playa are the principal areas for this subtype. A Tarbush (*Flourensia cernua*) subtype indicates the Chihuahuan Desert influence of the eastern portion of the study area. The Tarbush subtype also contains *Acacia vernicosa*. The other two subtypes do not occur within the study area.

Lowe (1961, 1964) considered the vegetation of Arizona to be broken down into "biotic communities" or "formation-classes" and their subdivisions. He followed the life-zone concept put forth by Merriam (1890, 1898). He has recognized three life-zones as occurring within the study area: Lower Sonoran, Upper Sonoran, and Transition.

The Lower Sonoran zone is equivalent to "desert" (Lowe, 1964). The Southwestern Desertscrub is the only formation occurring within the study area. The Sonoran Desert component has two "communities" occurring within the study area: the Creosotebush and the Paloverde Communities. Both types have already been discussed. The Chihuahuan Desert component has four major communities or "association-types" recognized as occurring within the study area. They are dominated by *Flourensia cernua*, *Larrea tridentata*,

Mortonia scabrella, and Acacia vernicosa. In many areas, Flourensia cernua, Larrea tridentata, and Acacia vernicosa are intermixed and may be associated with Koeberlinia spathulata, Rhus microphylla, Fouquieria splendens, Prosopis juliflora, Condalia spathulata, and Parthenium incanum.

The Upper Sonoran zone includes woodland, chaparral, and grassland (Lowe, 1964). Grasslands range from essentially pure grass landscapes to mixed grass-shrub. Chaparral consists of the same species as have been mentioned previously (with the exception of the addition of Cowania mexicana by Lowe). Woodlands range from the Open Evergreen Woodland to Encinal to Pine-Oak Woodland. "Encinal" refers to an oak woodland of Sierra Madrean origin dominated by Quercus spp., Juniperus spp., and Pinus cembroides. Deciduous woodland occurs along streambanks and floodplains. It is composed chiefly of Populus fremontii, Platanus wrightii, Fraxinus velutina, Juglans major, and Salix spp. The Transition zone vegetation barely extends into the study area; it is equivalent to the pine forest.

One of the major works on the vegetation of southeast Arizona is that of Darrow (1944). His study was on Cochise County (essentially the eastern half of the study area lies within Cochise County). Darrow identified seven "range" types occurring within the study area. As his hierarchical arrangement of types and subtypes is

very difficult to follow they will be presented in outline form.

Oak Woodland

Oak Woodland Type - This type covers the lower mountain slopes from 4,500 feet to 7,000 feet. Major species include *Quercus emoryi*, *Q. oblongifolia*, *Q. arizonica*, *Q. hypoleucoides*, *Juniperus deppeana*, *J. monosperma*, and *Pinus cembroides*.

Streambank and Floodplain Vegetation Type

Woodland-Grassland Type

Chaparral and Mountain Browse Type - This type is dominated by *Arctostaphylos* spp. and *Cercocarpus breviflorus*. Other important species include *Rhus trilobata*, *Quercus turbinella*, *Nolina microcarpa*, and *Garrya wrightii*.

Grassland

Grassland Type

High Elevation Grama (*Bouteloua* spp.) - Curly Mesquite (*Hilaria belangeri*) Subtype

Low Elevation Grama Subtype

Tobosa (*Hilaria mutica*) and Sacaton (*Sporobolus wrightii*) Subtype

Grassland - Mountain Browse Type - This type is transitional between the chaparral oak woodland belt and the grassland belt. *Nolina microcarpa*, *Ceanothus greggii*, and *Quercus* spp. are important species included with the grasses.

Grassland - Mesquite Type - predominantly Bouteloua spp. with considerable Prosopis juliflora.

Grassland - Desert Shrub Type

Subtype A - Shrubs consist primarily of Fouquieria splendens, Dasylirion wheeleri, Agave spp.; cacti are also present.

Subtype B - Shrubs consist primarily of Yucca spp., Ephedra trifurca, and Acacia greggii.

Subtype C - Shrubs consist primarily of Acacia vernicosa, Flourensia cernua, Larrea tridentata, and Prosopis juliflora. The principal grass species of this subtype is Hilaria mutica. Grasses must predominate the type.

Grassland - Half Shrub Type - Bouteloua spp. and Hilaria mutica with the half shrubs consisting of Haplopappus tenuisectus and Gutierrezia sarothrae.

Half Shrub - within the grassland belt.

Burroweed Type - Burroweed (Haplopappus tenuisectus) dominates, annual grasses present.

Snakeweed Type - Snakeweed (Gutierrezia sarothrae) dominates, annual grasses present.

Mesquite

Mesquite Bottomland Type - dense groves of Prosopis juliflora with Celtis reticulata, Condalia lycioides, Haplopappus tenuisectus, Baccharis glutinosa, and B. sarothroides.

Mesquite - Grassland Type - Prosopis juliflora frequently with Acacia vernicosa, and Bouteloua spp.

Mesquite - Half Shrub Type - Prosopis juliflora with an abundant cover of Haplopappus tenuisectus or Gutierrezia sarothrae.

Creosotebush

Creosotebush Type

Creosotebush Subtype A - Larrea tridentata in nearly pure stands.

Creosotebush Subtype B - Larrea tridentata with Flourensia cernua, Acacia vernicosa, and Prosopis juliflora.

Creosotebush - Grassland Type - similar to the Creosotebush Subtype A except that Bouteloua spp. and Hilaria mutica constitutes an important undercover.

Desert Shrub

Desert Shrub Type - composed of mixtures of Flourensia cernua, Acacia vernicosa, Larrea tridentata, and Prosopis juliflora. The type is commonly found on the calcareous scils of the San Pedro River drainage.

Desert Shrub - Grassland Type - dominated by the same shrubs listed immediately above with the addition of Mortonia scabrella, Bouteloua spp., and Aristida spp.

Subtype A - steep rocky slopes. Additional species present include Dasylirion wheeleri, Aloysia wrightii, Agave spp., and Fouquieria splendens.

Subtype B - level or gently rolling topography. Yucca spp. are an important additional component.

One of the few attempts to classify the vegetation of a portion of the study area region on the basis of numerical taxonomy principles was that of Garcia-Moya (1972). His work was based on a study of an approximately 250 square-mile area surrounding the city of Tombstone. Summarizing Garcia-Moya's classification, the vegetation consists of "three alliances and four unallied associations". The three alliances (roughly considered as broad classes of vegetation) are: Acacia vernicosa-Larrea tridentata-Flourensia cernua (approximately equivalent to Desert Shrub), Bouteloua eriopoda-Yucca elata, and Fouquieria splendens-Acacia constricta-Aloysia wrightii. The four unallied associations included in the classification were a Hilaria mutica type, a Haplopappus tenuisectus - Eragrostis lehmanniana type, an Agave spp. - Haplopappus laricifolius type and a Mortonia scabrella type.

Summarizing existing classifications, it can be said that most are far too general to be of value to this research. Only five of Shreve's "nine principal types of vegetation" (1964) are found in my study area. Four of Humphrey's divisions of vegetation (1960) and only three of Nichol's basic types of vegetation (1937) occur in my study area. Lowe's classification (1964) which was based partially

on the lifezone concept is too ambiguous to be directly applied to my observations of vegetation in my study area. Darrow's study (1944) was one of the most detailed classifications of the vegetation within my study area. It was developed to assist range management practices in Cochise County. One of its drawbacks was its limited scope (restricted to Cochise County). Garcia-Moya's classification (1972) was based on a study of a very small area (250 square miles) and was based upon a detailed analysis which included annual species identifiable at only very limited times during the year.

III. SELECTED LITERATURE REVIEW

This literature review will cover only the aspects of relationships between terrain variables and vegetation pertinent to this study. While it is recognized that other types of studies have been conducted in the general field of terrain variable - vegetation relationships, those studies seem largely, with one exception, irrelevant to this particular study.

An important series of studies on terrain variables and vegetation was conducted by Kassas *et al.* in Egypt. Those studies have considerably influenced the thinking of this author. It is therefore felt that some mention of Kassas' work be given recognition here. Kassas' major effort was on habitat and plant communities in the Egyptian desert (Kassas, 1952, 1953, 1956, 1957, 1959, 1960, and 1962; Kassas and El-Abyad, 1962; Kassas and Girgis, 1964, 1965, and 1970; and Kassas and Imam, 1954 and 1959).

Kassas felt that each "community type" needs to be referred to a discrete habitat type as a prerequisite to its identity. The community type is a unit of an ecosystem -- an "ecocoenosis" (see, for example, Kassas and Girgis, 1965). Kassas found that the vegetation of Egypt was affected by water availability which, in turn, is influenced by landforms. As a result, the vegetation follows rather discrete patterns of landforms and concomitant moisture

availability. Kassas recognized three basic geomorphic divisions in northeastern Egypt (his study area): drainageways (wadis), sand and gravel deserts, and hardrock erosional surfaces (hamadas) generally composed of limestone. Each of those geomorphic divisions has an array of community types or ecogeomorphic systems dependent upon the degree of succession (frequently a function of soil development) and moisture availability.

In southeastern Arizona, terrain variable - vegetation studies can be considered in the context of the types of individual variables studied.

Two of the most common terrain variables associated with vegetation have been elevation and exposure (slope aspect). The observation that vegetation changes with elevation has essentially resulted in the life zone concept (Lowe, 1964). Shreve (1915, 1922, and 1924), Haase (1970), Whittaker and Niering (1965, 1968a, and 1968b), and to an extent Benson and Darrow (1954) directly addressed their studies to the examination of the effects of elevation and exposure on vegetation. Shreve (1915) stated that the upper limit of species was considerably higher on north - facing slopes than on south - facing slopes. He showed that the influence of slope exposure was greater with increasing elevation. He felt that the effect of altitude on vegetation was through moisture factors, temperature factors, and light factors. Whittaker and Niering arrived at

similar conclusions. They showed that ravines depressed elevational ranges of species by a couple of thousand feet. Species tended to occur approximately one thousand feet lower on north - facing slopes than on south - facing slopes.

Cumming (1951) in a study on The Effect of Slope and Exposure on Range Vegetation in Desert Grassland and Oak Woodland Areas of Santa Cruz County, Arizona found that both perennial grass as well as shrub density was greater on north aspects than on south aspects. Annual grasses had low densities on all sites. Cumming noted that Quercus spp. were more abundant on north aspects than on south aspects while Mimosa dysocarpa and Prosopis velutina (later Prosopis juliflora) occurred more or less evenly over all aspects (I found that Mimosa dysocarpa occurs predominantly on south - facing slopes). Cumming concluded that the effect of aspect on vegetation was through its effect on soil moisture and soil temperature.

Several studies on relationships between vegetation and parent materials and/or landforms in southeastern Arizona have been conducted (Bradbury, 1969; Shantz and Piemeisel, 1924; and Zimmermann, 1969). Other studies have included some information on those relationships (Benson and Darrow, 1954; and Darrow, 1944).

Bradbury (1969) in a study on Vegetation as an Indicator of Rock Types in the Northern Swisshelm Mountains, Southeastern Arizona, concluded that eight species were not only reliable

indicators of rock type, but were also relatively common in his limited (approximately two square miles) study area. Those species were Ceanothus greggii, Condalia spathulata, Cowania mexicana, Dalea formosa, Mortonia scabrella, Parthenium incanum, and Quercus pungens on limestone, and Quercus toumeyi on rhyolite.

Zimmermann (1969) undertook a study of Plant Ecology of an Arid Basin, Tres Alamos - Redington Area, Southeastern Arizona. Half of his 750 square mile study area lies within the north central portion of my study area. Zimmermann found striking variations in the vegetation occurring at similar altitudes. He attributed those variations to differences in moisture regimens in different substrates. He noted that on undissected slopes, the soils supported small trees (mainly Prosopis juliflora and Acacia spp.) and a grass cover, while dissected slopes supported only stands of shrubs (mainly Larrea tridentata) without grasses. Zimmermann noted that drainage area, geology, and flow regimen are probably the three most important controls in the distribution of valleyfloor vegetation.

IV. METHODS

Data Collection

Prior to the specific collection of data for the analysis of the relationships between terrain variables and vegetation, several reconnaissance transects of the study area were conducted. The purpose of these trips was to acquire general knowledge of possible vegetation types, to become familiar with the flora, and to consider the terrain variables. The degree of familiarization obtained of the study area during those various trips was of great assistance in establishing the subsequent system of data collection and analysis.

In order for these relationships to be studied objectively, it was felt that data should be collected from samples drawn from a stratification of one or more of the variables to be examined. Those variables were chosen from the terrain features rather than from the vegetation. The reason for this sampling was because one of the ancillary purposes of the investigation was ultimately to infer vegetation from the terrain variables.

It was decided that the most objective and readily mapped terrain variables were elevation and parent materials. Although elevation per se is objective and mappable, it also correlates well with precipitation and soil moisture, which in turn correlate well

with vegetation. Elevation classes established for the stratification were chosen with 500 foot contour intervals separating the classes (although the 5, 500 foot contour was deleted for the establishment of the highest class). The upper limit chosen was 6, 000 feet and the lower limit was approximately 2, 600 feet - approximately the elevation of the valley-fill plains immediately to the southeast of Tucson (i. e., the northwest corner of the study area). The elevation classes, therefore, are as follows:

Elevation Class	Range
1	2, 600 feet to 2, 999 feet
2	3, 000 feet to 3, 499 feet
3	3, 500 feet to 3, 999 feet
4	4, 000 feet to 4, 499 feet
5	4, 500 feet to 4, 999 feet
6	5, 000 feet to 5, 999 feet

The upper limit did not exceed 6, 000 feet on account of the very limited area of terrain extending above that elevational level, as well as the extreme difficulty of assess to the higher elevations. It was also considered that relationships between terrain variables and vegetation could not be accurately drawn from so small a sample as from the areas lying above 6, 000 feet. A map of elevation according to the established classes listed above was then constructed at a

scale of 1:250, 000. USGS topographic maps form the basis for that map.

Parent material information was obtained from geological maps available for the study area (Arizona Bureau of Mines; 1960, 1962). Five classes of parent materials were chosen and were then mapped at a scale of 1:250, 000. Those classes are:

Class	Parent Material
1	Alluvium
2	Sedimentary (other than limestone)
3	Limestone
4	Intrusive igneous (and metamorphics)
5	Volcanics

Intrusive igneous parent materials were primarily acid igneous rocks. Metamorphics, consisting almost entirely of schist, gneissic granite, granitic gneiss, and gneiss, were also included in this class. Volcanics consisted of andesite, rhyolite, and a wide variety of gradations of the two.

At this point in the data collection, field gathering of the data was initiated. However, in order to preserve the contiguity of the discussion of all terrain variables studied, the remaining six variables will be described. This will be followed by a description of field data collection techniques employed in the study.

The concept of macrorelief refers to the general gross relief of an area. Local relief, relative dissection, and slope angle are included in the concept. Generally speaking, regional slope combines with local relief in determining classes. The following represents the classes of macrorelief developed and recognized in the study area:

Flat lands - A generally flat landscape with prominent slopes <10%.

1. essentially smooth. Dissection is minimal. The regional slope is nearly always between 0 and 3%.
2. relatively flat. However, dissection has progressed to a noticeable point. Dissection is either widely spaced (in which case side slopes may be over 10%) with sharp angles, or more closely spaced with a gently rolling topography. Where side slopes exceed 10%, local relief is generally less than ten feet.

Rolling and Moderately Dissected Lands - prominent slopes 10 to 25% (side slopes may exceed that figure in the case of dissected planar surfaces).

3. A moderately to strongly dissected planar surface (i.e., pediment, bajada, valley-fill, etc.). The regional slope is generally between 2 and 6%; side slopes must be steeper than 10%. If side slopes are steeper than 25% (which is relatively common in the study area), relief must be less

than 100 feet. The drainage network is generally finer than that of class No. 2.

4. rolling or hilly; a regional slope is not readily apparent unless it is between 10 and 25%. Relief must be less than 100 feet.

Hilly lands

5. hilly to submountainous; slopes are moderate to steep, usually exceeding 25%. Relief is generally over 100 feet but less than 1,000 feet. Where relief approaches 1,000 feet, the topography appears fairly homogeneous.

Mountainous lands

6. mountainous, having high relief, usually over 1,000 feet. Slopes are moderate to steep, frequently exceeding 50%. The landform system appears quite complex and heterogeneous. The drainage networks usually have base levels independent of one another.

The descriptions for landforms were listed and classes developed to handle them. It is recognized that the landform classes were nonparametric and therefore it was not possible to use them in a meaningful way in analyses that considered data in a parametric fashion. Classes of landform type were selected on the basis of environmental significance, facility for remote sensing interpretation, and acceptance by other geomorphologists. The landform type

classes describe either the morphologic character of a particular surface, a morphogenetic character of the surface, or a relative position of that surface with respect to other similar surfaces. The classes of landforms follow:

LANDFORMS DEVELOPED UPON
NON-CONSOLIDATED MATERIALS

Class	Landform
01	swale
02	floodplain
03	narrow floodplain
04	alluvial terrace
05	valley-fill
06	dissected valley-fill
07	lacustrine plain
08	sand dunes
09	wash
10	undifferentiated bajada
11	upper bajada
12	lower bajada
13	undifferentiated dissected bajada
14	convex slope of dissected bajada
15	midslope of dissected bajada
16	interfluve (area between adjacent drainageways, not included in other classes)

LANDFORMS DEVELOPED UPON
CONSOLIDATED MATERIALS

Class	Landform
21	upper convex hillslopes
22	upper-middle hillslopes
23	middle hillslopes
24	lower-middle hillslopes
25	lower concave hillslopes
26	interfluve
27	drainageway
28	pediment

In the first series of analyses, the landform classes as listed above were used. Later, it was decided to combine classes of landforms; these combinations will be mentioned in a subsequent chapter.

Drainage density is the ratio of total lengths of drainageways of a sampled site to the area of that sampled site. It is a measure of relative dissection of a landscape as well as an indicator of internal drainage characteristics. An area having a high drainage density tends to be better drained than an area with a low drainage density. Drainage density values in the study area ranged from 0 to 14.3 miles per square mile. Classes of drainage density values were established so as to assign interpretations of low, medium, and high values to the quantitative indicators of drainage density. Those classes were:

Drainage Density Class	Value
1 (low Dd)	< 5.0 mi/mi^2
2 (medium Dd)	5.0 - 7.2 mi/mi^2
3 (high Dd)	> 7.2 mi/mi^2

Slope angles measured in the field (with a Brunton compass to the nearest 1/2%) ranged in value from level to over 100%. As values of slope angle were not equally distributed throughout the range, classes were devised in order to reflect basic geomorphic differences within the study area. The classes fell into an approximate geometric progression. The following classes were recognized:

Class	Slope Angle	Geomorphic Significance
1	0 - 1%	level surfaces (playas, valley-fill)
2	1 1/2 - 3%	undissected bajada surfaces
3	3 1/2 - 10%	upper bajadas and pediment surfaces
4	11 - 25%	gentle hills; some side slopes of dissected bajadas
5	26 - 50%	hill slopes; typical side slopes of dissected bajadas
6	over 50%	steep hill slopes, talus, bare rock surfaces, cliffs, and some of the steeper side slopes of dissected bajadas

Slope aspect was measured in the field with a Brunton compass. Values of slope aspect were rounded to the nearest 1/8 compass point. Values were ordinated with respect to their relative moisture condition. The southwest class was considered to be the most xeric (Geiger, 1957; Whittaker, 1965) and therefore was assigned a value

of "1". The northeast class was considered to be the most mesic and therefore was assigned a value of "9". The level class was developed to include slopes of less than 3 1/2%. It was considered intermediate in moisture condition and was placed in the middle. The aspect classes were as follows:

Aspect Class	Aspect
1	southwest
2	south
3	west
4	southeast
5	level
6	northwest
7	east
8	north
9	northeast

Values of potential solar beam irradiation of the surface were assigned to each site (after Frank and Lee, 1966). These values are obtained from slope aspect and slope angle data. One of the chief influences of slope angle and slope aspect on vegetation is through the solar radiation incident on the vegetation as well as on the ground. An index of solar radiation indicates that combined effect. The solar radiation index, in this thesis expressed as a percent, is the ratio of the total annual potential insolation to the maximum potential insolation at the site. In the study area, the

maximum value on steep south slopes is 60 1/2%, while the maximum value observed on steep north slopes was 24%. The value on a level surface is 52.7% (Frank and Lee, 1966). The following classes of solar radiation were developed:

Class	SR Index
1 (low SR)	< 51%
2 (medium SR)	51 - 54%
3 (high SR)	> 54%

Field Data Collection Techniques

A sampling system was needed in order for field data collection to begin. Initially, the map showing elevation classes was superimposed on the map showing parent material types. The result was a combination of elevation and parent material units. A fine dot grid was placed over the resultant map for purposes of calculating the areas of elevation and parent material units. The area of each unit was then recorded and a percentage of total area attached to each unit. The total number of field samples chosen, 250, was arrived at on the basis of two primary considerations. The first was that there would be approximately 25 different vegetation types (that figure was determined from previous field reconnaissances, and advice from my colleagues). 250 field samples would allow for ten samples per type. The second consideration was that time and financial constraints limited field work to an interval in which some

200 to 300 field samples could physically be gathered. The 250 potential field samples were divided and assigned to elevation and parent material units on the basis of the area of each unit. The minimum number of potential field samples was three.

Potential field samples were selected on the basis of relative access by pick-up truck. They were plotted on 1:120, 000 scale aerial photographs. Field sample points were transferred to topographic maps at a scale of 1:62, 500. Final selection on the topographic maps took into account slope aspect.

Field data were collected on macrorelief, landform type, and soils. Slope aspect was measured with a Brunton compass and recorded to the nearest 1/8 compass point (i. e. north, northeast, east, etc.). Slope angle was also measured with a Brunton compass and recorded to the nearest 1%; slopes gentler than 3 1/2% were recorded to the nearest 1/2%. Elevation was estimated from topographic maps while in the field. Parent material was also determined in the field. Soil pits were dug at each site and soil samples were collected near the surface, at six inches depth, and at twelve inches depth. Surface soil color (primarily dry hue, value, and chroma) was recorded using a Munsell soil color chart.

Values of drainage density were determined from air photos and assigned to each field sample. The area chosen to compute the drainage density value was a circle with a one mile radius.

Drainageways were photointerpreted at a scale of 1:120,000 with stereoscopic reinforcement. All interpretable drainageways were included in the compilation of the drainage density values. If the one mile radius circle included landform types different from the type at the field sample site, that portion of the circle would be deleted from the computation. Values of potential solar beam irradiation (after Frank and Lee, 1966) were assigned to each field sample site in the office.

Vegetation data included the recording of prominence and cover values for all species observed at the time of the field data collection, at the suggestion of C. E. Poulton. Definitions of prominence and cover come from Poulton, et al., 1971:

> Prominence rating: Past usage of the common five-unit scale of "abundance" involved vague meanings of "very abundant", "common", "rare", etc. More precisely defined "prominence classes" to facilitate rapid but meaningful recording of the visual appearance, aspect, or physiognomy of the plant community have been developed. These ratings are to be based on the entire community taken as a unit, not on the separate layers. The rating symbols follow:

Prominence Rating	Description of Class or Meaning of Symbol
5	The most prominent species in the stand; the most obvious species in terms of amount present. Impression on the observer is that there is clearly more of the subject species than any other. Some stands may not have a species that clearly rates "5" and the class would be omitted.

Prominence Rating	Description of Class or Meaning of Symbol
4	The second most prominent species in the stand or one of a group of species that share about equally in being most prominent (in which case each is accorded a prominence of "4"). All remaining species are less prominent than the subject species.
3	A rather uniformly distributed species that is easily seen by standing at one place and looking casually around. Species may fall into this class if they are initially hard to see because of small stature but once located are easily seen. Usually there are numerous species accorded a prominence of "3".
2	A species that can be seen only by looking intently while standing in one place or by moving around in the stand. Species occurring in patches encountered by moving about would be rated in prominence class "2" even though, within a patch, they may rate a higher prominence score. Not so rare that one must look in and around other plants to see the species.
1	Species that can be seen only by searching for them in and around other plants. Considerable care is required to find species rating prominence class "1". Species which occur in extremely wide-scattered small patches or clumps of individuals would rate a prominence "1" provided they do not represent an "inclusion" of a different plant community (vegetation type).

Cover classes: These are normal crown-spread cover values recorded for each species individually without mentally or physically compressing the foliage. All area within the peripheral circumference is assumed to be completely covered. The estimate is a total of the vertical projection of these values for the species. According to this system, total cover percent may exceed 100 percent. This is frequently the case in desert

and deteriorated steppe environments. The rating symbols follow:

Cover Class	Cover Percent	Mid-Point Value
1	0+ - 1	0.5
2	1+ - 5	3.0
3	5+ - 10	7.5
4	10+ - 25	17.5
5	25+ - 50	37.5
6	50+ - 75	62.5
7	75+ - 95	85.0
8	95+ - 100	97.5

This system can be used with high effectiveness and consistency by workers in either a plotless or a sample plot method. Steppoint and related methods are entirely unsatisfactory for legend development because they are biased toward high-density, frequent species, and they do not register nearly all the species at normally used sampling intensities.

In my study, the ground observations were taken from homogeneous units of vegetation in a plotless method. In terms of area, the "stand" sampled would be approximately 25 to 50 meters in diameter.

Included in the preparation of the data for analysis was the classification of the vegetation. That the classification of vegetation should be included in "Methods" and not "Results" should be obvious: it was not the goal of the research, only a means toward attaining that goal.

Vegetation Classification

Two general analyses of vegetation and terrain variables were

conducted in the thesis research. The first series of analyses involved the relationships between individual species and terrain variables. Numerical values for species in this series of analyses consisted of values for cover classes.

The second series of analyses involved the determination of relationships between vegetation types and terrain variables. This necessitated the prior development of a vegetation classification, as none was available and this thesis partially rests upon the use of that classification. However, it is to be made clear at this point, that the development of that classification was only a means of acquiring information which could be used for later analysis and the classification itself was not a specific goal of the thesis. Had it been possible to devise a unified classification from the diversity of viewpoint in the literature, considerable time would have been saved, yet the specific goals of the thesis would have remained unaltered.

Although various kinds of data including plant species data were collected for approximately 1,200 locations in and adjacent to the study area, sample locations were reduced to approximately 500 for the development of the vegetation classification.

Each field sample write-up included species presence and prominence data (Poulton, Johnson, and Mouat, 1970).

The first stage in the vegetation classification consisted of a reconnaissance of the area and a review of literature (Darrow, 1944; Humphrey, 1960, 1963; Interagency Technical Committee - Range -, 1963; Lowe, 1964; Nichol, 1952; Pond and Bohning, 1971; Shreve, 1942; and Shreve and Wiggins, 1964). On the basis of that review, lists were compiled of those plant species which seemed to best typify broad vegetation classes. Six of these broad classes were developed: Sonoran and Chihuahuan Desert shrub, grassland, chaparral, mixed needleleaf and broadleaf woods, and needleleaf forest.

The approximately 500 field samples were sorted within the six broad classes to produce subgroups when warranted by the similarities and differences among the samples. The subgroups can be considered as a finer level of detail than the broad classes. The criteria for sorting within the subgroups were species presence and prominence. Vegetation classification work by Garcia-Moya (1972) for a small portion of the study area provided some useful guidelines for the sorting activities. As subgroups became evident, association tables were prepared which provided the means for making final decisions about the validity of the subgroups. The resulting classification is based primarily upon the presence or absence of the more common plant species and, secondarily, on the prominence of those species. Each association table showed

C, 2

the species present and their prominence ratings for all field samples belonging to one subgroup. Those tables provided the compiled data for the recognition of character and differential species and the vegetation descriptions which shortly follow. The vegetation classification was not based upon prior subjective attitudes I had developed regarding the relationships between and among vegetation and terrain variables. The classification was based entirely upon the vegetational characteristics mentioned previously.

Thirty-one subgroups were ultimately established and can be considered to be "vegetation types". Throughout the remainder of this thesis the term "vegetation type" will be used to indicate the final set of vegetation units arrived at by the classification scheme (a modified Braun-Blanquet type analysis). It is to be further mentioned here that no attempt was made or is being made to equate those vegetation types with either "habitat type" or "plant association" (Daubenmire, 1968). It is possible that some phytosociologists might find one or more of the vegetation types to be at the phytosociologic association level. Other vegetation types might be found to be in a higher or lower position in the hierarchical arrangement of vegetation classes.

The vegetation type descriptions conform to a uniform format and consist primarily of elaborated discussions about the plant species. The physiognomy of a group is given first, followed by a

discussion of those species, having high presence, which characterize the vegetation type. This is followed by a consideration of species within life forms in the following order: trees, shrubs, succulents, and herbs (i. e. grasses). These discussions of species include prominence ratings and a qualitative indication of the regularity (species presence percentage) with which species may be expected to be present among the stands of the vegetation type. The description may be concluded by comments pertaining to the relationship of the type in question to other types. The photographs used to illustrate each vegetation type were selected to represent the type.

These descriptions are taken from a report of research undertaken by Schrumpf, Johnson, and Mouat (1973).

Twenty-five of the thirty-one identified vegetation types were used in the data analyses and have been indicated by abbreviated symbols following each vegetation type title.

The absence of some species was noteworthy in the identification of many of the vegetation types. As such the use of the negative "without" was used in parenthetical expressions in the titles for each vegetation type.

Data Analysis

Two general analyses were conducted on vegetation and terrain variables. One of these involved the relationships between

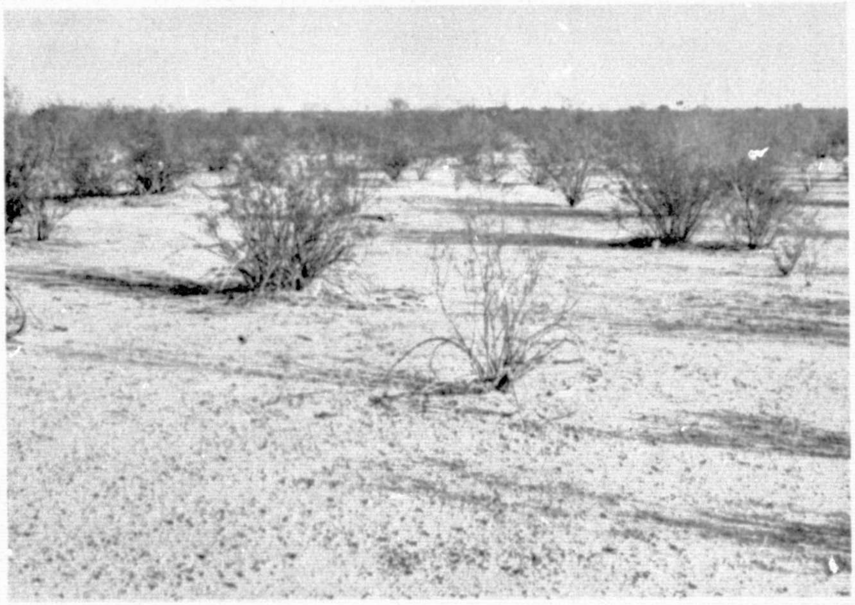


Figure 8. Larrea tridentata (with or without annuals).

This vegetation type has a "shrub-scrub"[a] physiognomy, specifically, "microphyllous, non-thorny scrub, generally with succulents."

Larrea tridentata occurs regularly spaced in nearly pure stands, giving a uniform appearance. However, annuals may be present during periods when sufficient moisture is available. Zinnia pumila and Tridens pulchellus may be present with low prominence values.

This vegetation type appears to be closely related to the "Larrea tridentata with Prosopis juliflora and/or Opuntia (cholla)" type. The two are often found in close proximity.

---

[a]The physiognomic terms are from the technical legend from Schrumpf, B. J., et al., 1973.

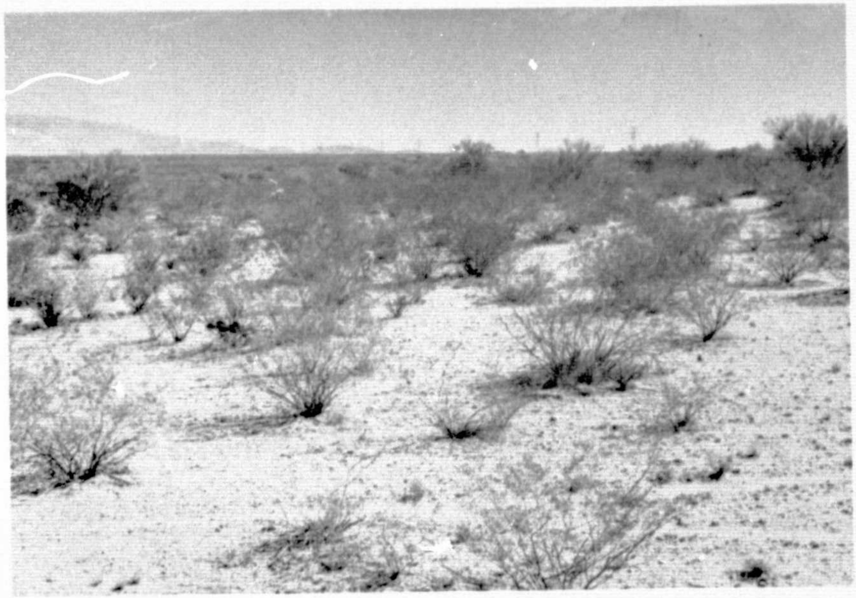


Figure 9. Larrea tridentata with Prosopis juliflora and/or Opuntia (cholla). (V. T. 2 = Latr)[a]

The physiognomy of the type is described in general as "shrub-scrub" and in specific as "microphyllous, non-thorny scrub, generally with succulents."

Larrea tridentata almost always maintains a high prominence value (5) in this type; however, other species of similar stature are present and often conspicuous. Prosopis juliflora is one of these. Cacti, especially cholla (mostly Opuntia fulgida) are also usually present and occasionally high in prominence.

Other tall shrub species are commonly present, but generally in low prominence (1-2). These include Fouquieria splendens, Acacia constricta, Cercidium floridum, and C. microphyllum, among others. The low statured Zinnia pumila is nearly ubiquitous and is often joined by Haplopappus tenuisectus and/or Coldenia canescens.

Stem succulents, as previously mentioned, are a characteristic feature of the type. The chollas (Opuntia fulgida and/or O. spinosior) are usually present with mid-prominence values (1-2).

Grasses are a conspicuous component of most stands. Tridens pulchellus is normally present and with prominence values of 3-4, while Muhlenbergia porteri is common and has low to mid-prominence values (1-3).

The type appears related to "Larrea tridentata (with or without annuals)."

---

[a]These vegetation types ("V. T.") are used in the analyses.

Figure 10. Cercidium microphyllum and Cereus giganteus often with Encelia farinosa and Opuntia, (without Franseria deltoidea). (V. T. 3 = Cemi)

This vegetation type has a "shrub-scrub" physiognomy, specifically, "microphyllous, non-thorny scrub, generally with succulents."

Cercidium microphyllum is usually prominent or coprominent (4) and is generally accompanied by Cereus giganteus, Encelia farinosa, and a variety of cacti. For purposes of type recognition, the absence of Franseria deltoidea need also be recognized.

A variety of shrub species may be present in this rather floristically rich type including Prosopis juliflora, Acacia constricta, Celtis pallida, Zinnia pumila, and Larrea tridentata. Most do not occur with high prominence values, but Larrea can achieve a high rank (4) in a few stands.

Several cacti species contribute to the type, with at least one occurrin in each stand. Prominence values rate mid-to-low. From most to least common, the cacti are Opuntia (prickly pear and cholla), and Ferocactus wislizenii.

An immense variety of forbs and grasses, both annuals and perennials, make a marked seasonal floral impression.

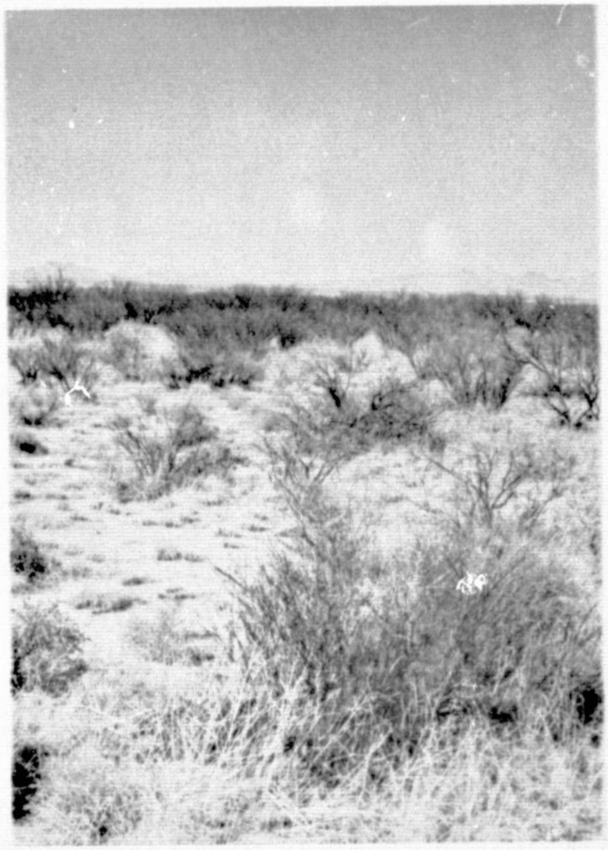


Figure 11. Atriplex canescens and Prosopis juliflora.

The physiognomy of this vegetation type is "shrub-scrub," especially "microphyllous saline tolerant and related scrub types."

Atriplex canescens and Prosopis juliflora occur together in restricted areas. The prominence values of the two species are quite variable (2-5), but in general one or the other or both tend to rank highest in prominence value.

The variety of other shrub species is generally limited, but may include Larrea tridentata, Haplopappus tenuisectus, Zinnia pumila, Opuntia (cholla), and Fouquieria splendens among others. Grass prominence values are generally not high, but several genera are often represented including Muhlenbergia, Sporobolus, and Andropogon.

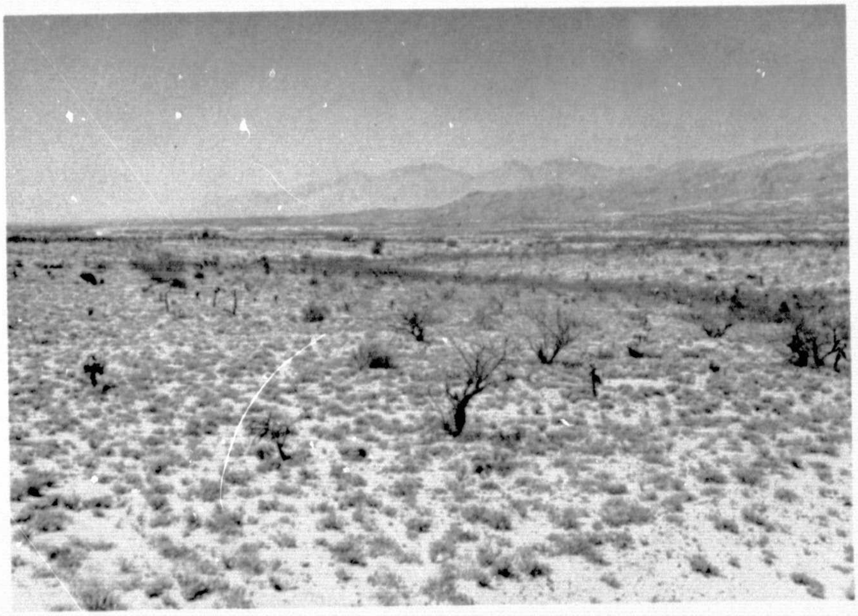


Figure 12. Coldenia canescens, Zinnia pumila, Fouquieria splendens, and Tridens pulchellus.

The vegetation of this type has a "shrub-scrub" physiognomy.

Coldenia canescens and Zinnia pumila clearly are the prominent shrubs in this type giving a low shrub aspect. Other low shrubs that may be present include Calliandra eriophylla, Ephedra trifurca, Psilostrophe cooperi, and Condalia lycioides. Their prominence values tend to be low. Taller shrubs are common, particularly Fouquieria splendens, Prosopis juliflora, and Acacia constricta, but they are never abundant enough to create a tall shrub aspect.

Succulents are also common and include some or all of the various Opuntia (chollas and prickly pear) and Yucca. Grasses, other than Tridens pulchellus and Muhlenbergia porteri are noticeably sparse.

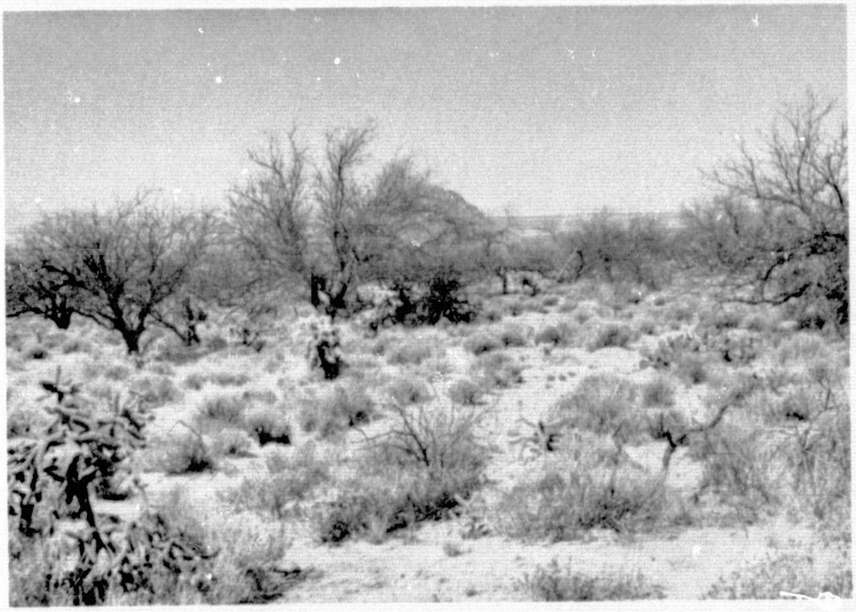


Figure 13. Prosopis juliflora and Haplopappus tenuisectus with Opuntia (cholla), (without Acacia constricta and Calliandra eriophylla). (V. T. 6 = Opun)

This vegetation type is classified as "shrub-scrub" and "microphyllous, non-thorny scrub, generally with succulents."

Prosopis juliflora and Haplopappus tenuisectus are the usual prominent (4-5) species of the type, with Prosopis the more common sole prominent (5) when the two are not coprominent. The consistent occurrence of Opuntia (cholla and prickly pear) with mid-to low prominence values (3-1) and frequent occurrence but low prominence value (2-1) of Ferocactus wislizenii further characterize the type. To distinguish from other types, the absence of Acacia constricta and Calliandra eriophylla needs to be noted. For the same reason, the low presence of Yucca elata is important.

Several shrub species, in addition to those mentioned above, are found in many of the stands, but none of these species occurs frequently or with high prominence values. The more common ones are Acacia greggii, Atriplex canescens, Cercidium floridum, Celtis pallida, Ephedra trifurca, and Fouquieria splendens.

Although grasses, primarily Aristida and Bouteloua, are common and fairly prominent (4-2), they are always decidedly subordinate to the shrubs.

This vegetation type is related to "Prosopis juliflora and Haplopappus tenuisectus, (without Acacia constricta, Opuntia (cholla), and Calliandra eriophylla)."

Figure 14. Prosopis juliflora and Haplopappus tenuisectus, (without Acacia constricta, Opuntia (cholla), and Calliandra eriophylla). (V. T. 7 = Prju)

The physiognomy of the type is "shrub-scrub," specifically "microphyllous, non-thorny scrub, generally with succulents."

In this type, which usually has a tall shrub or low shrub aspect, Prosopis juliflora is the most common tall shrub while Haplopappus tenuisectus is the most common low shrub. In most stands these species are either prominent (5) or coprominent (4) with grasses (Bouteloua and/or Aristida). One of the character features of the type is that it has very few shrub species other than those mentioned, and in particular it never has Acacia constricta or Calliandra eriophylla. Furthermore, cacti are nearly absent. Opuntia (prickly pear), when present, has low prominence values. Yucca elata is common with mid-to low prominence values.

A great variety of grasses is found in the type. Occasionally, individual grass species will rank highest in prominence value. The most common species are Bouteloua rothrockii, B. curtipendula, B. eriopoda, Andropogon barbinodis, Muhlenbergia porteri, and several species represented by the genera, Aristida, Eragrostis, and Setaria.

A related type is "Prosopis juliflora and Haplopappus tenuisectus with Opuntia (cholla), (without Acacia constricta and Calliandra eriophylla)."

Figure 15. Calliandra eriophylla usually with Acacia constricta, Fouquieria splendens, and Prosopis juliflora, (without Coldenia canescens). (V. T. 8 = Caer)

Stands of this type always have a "shrub-scrub" physiognomy.

Although this type is characterized by Calliandra eriophylla, this species is seldom prominent and, in fact, may occupy a position of low prominence. The aspect of the type is most often one of mixed tall shrubs. Acacia constricta, Fouquieria splendens, and occasionally Prosopis juliflora share, or alternately solely occupy, the most prominent position. In some stands, any one of the three species can be absent. Except for the species mentioned above, few other shrub species contribute substantially to the type, although several can be present. The more common of these are Zinnia pumila, Acacia greggii, and Lycium. The near absence of Haplopappus tenuisectus and complete absence of Coldenia canescens aid in distinguishing this type from others.

Opuntia (primarily prickly pear and some cholla) is the primary succulent. Prickly pear is present in most stands with mid-prominence values. Ferocactus wislizenii, although in low prominence, is commonly a component.

Grasses are common, and frequently have higher prominence values than shrubs. As is often the case, species from the genera Aristida and Bouteloua are abundant. Two of the most common species are Bouteloua curtipendula and Hilaria belangeri.

This type is closely related to "Acacia constricta and Prosopis juliflora usually with Opuntia, (without Calliandra eriophylla)."

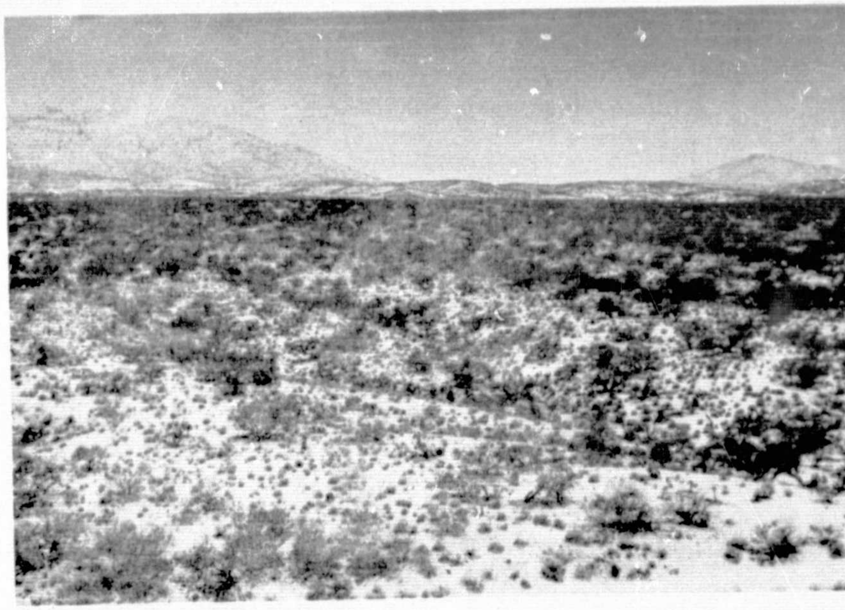


Figure 16. Acacia constricta and Prosopis juliflora usually with Opuntia, (without Calliandra eriophylla). (V. T. 9 = Acco)

The physiognomy of this type is "shrub-scrub."

Acacia constricta is always present in this type which is further characterized by almost always having Prosopis juliflora. These two species are generally the most prominent. Opuntia (cholla and/or prickly pear) contribute to the type. The absence of Calliandra eriophylla needs to be recognized to help distinguish this type from some similar types.

A notable feature of the type is its extreme floristic diversity, particularly among shrubs. Some of these are Acacia greggii, Celtis pallida, Cercidium floridum, C. microphyllum, Ephedra trifurca, Fouquieria splendens, and Larrea tridentata. In most cases these species are present and have mid-to low prominence values (3-1).

Grasses, like the shrubs, are present in variety, but generally not in high prominence. The genera Aristida and Bouteloua are best represented along with the species Tridens pulchellus and Muhlenbergia porteri.

This vegetation type is similar to "Calliandra eriophylla usually with Acacia constricta, Fouquieria splendens, and Prosopis juliflora, (without Coldenia canescens)."

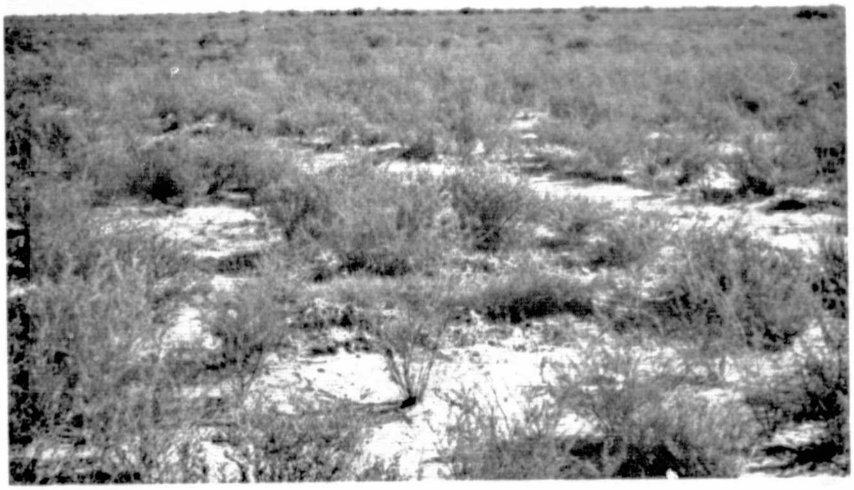


Figure 17. Acacia vernicosa, Flourensia cernua, and Larrea tridentata, (without Rhus microphylla and Dalea formosa). (V. T. 10 = Acve)

The physiognomy of this type is "shrub-scrub," specifically "microphyllous thorn scrub."

The three species which characterize the type are the shrubs, Acacia vernicosa, Flourensia cernua, and Larrea tridentata. All three are usually present with one of the three being most prominent or at least two of the species sharing prominence. The absence of Rhus microphylla and Dalea formosa needs to be recognized to prevent confusion with a similar type.

In addition to the shrub species mentioned, several others may be present including, but not limited to, Zinnia pumila, Parthenium incanum, Fouquieria splendens, and Prosopis juliflora. These species usually have mid-to low prominence values.

The primary leaf succulent is Yucca elata which is present only occasionally. Stem succulents are not common in the type, with Opuntia phaeacantha most often present.

Perennial grasses are usually present, and usually in mid-to low prominence. Bouteloua eriopoda and Muhlenbergia porteri are usually present, and Hilaria mutica occasionally is. The biennial grass, Tridens pulchellus, usually is present.

This vegetation type is closely related to the one identified as "Acacia vernicosa, Flourensia cernua, Larrea tridentata, and Rhus microphylla."

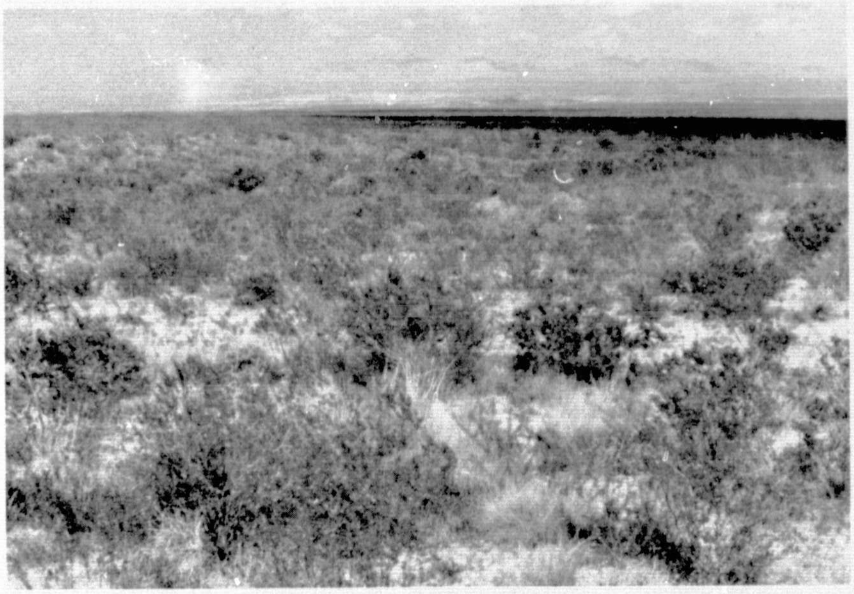


Figure 18. Acacia vernicosa, Flourensia cernua, Larrea tridentata, and Rhus microphylla. (V. T. 11 = Rhus)

"Shrub-scrub" ("microphyllous thorn scrub") is the physiognomy of this vegetation type.

The shrub, Rhus microphylla, is always present in the type, usually with mid-prominence values. In most stands, two or more of the other three characteristic shrub species (Acacia vernicosa, Flourensia cernua, and Larrea tridentata) are present, and one of these will occupy the position of highest prominence. Any of several other shrub species may be present, but they usually have mid-to low prominence values (3-1). Zinnia pumila and Parthenium incanum are very common. Some of the other species which are occasionally present include Condalia spathulata, Ephedra trifurca, Fouquieria splendens, Koeberlinia spinosa, and Krameria parvifolia.

Leaf succulents may be present but usually are in low prominence. The more common species are Yucca baccata, Y. elata, and Nolina microcarpa. Stem succulents are rare.

Perennial grasses are common with the genera, Aristida, Bouteloua, and Muhlenbergia most frequently represented. Tridens pulchellus is the most common grass species and it is usually present. Prominence values of individual grass species cover the range (5-1), but most range from 3 to 1.

The type is related to and resembles "Acacia vernicosa, Flourensia cernua, and Larrea tridentata, (without Rhus microphylla and Dalea formosa)."

Figure 19. Aloysia wrightii usually with Fouquieria splendens, Acacia constricta, and Opuntia (prickly pear). (V. T. 12 = Alwr)

This vegetation type has a "shrub-scrub" physiognomy and varies from "microphyllous thorn scrub" to "microphyllous, non-thorny scrub, often with succulents."

The most prominent species generally vary among Fouquieria splendens, Aloysia wrightii, and Acacia constricta and their combinations, although the latter is frequently absent. Grass prominence, especially Bouteloua, can be high (4-3). Opuntia (prickly pear), although rarely prominent (values mostly 3), is the remaining species which serves best to characterize the type.

Type variation can be regionally correlated. Toward the southeast portion of the study area Parthenium incanum, Flourensia cernua, Larrea tridentata, Mimosa dysocarpa, Acacia vernicosa, and Dasylirion wheeleri may be included in the type although they are by no means always present or abundant. Cercidium floridum, when present in this type, is confined to the western portion of the area. In addition, Lycium, and Celtis pallida, although only occasionally present, are confined to the west. Shrubs common throughout the type include Calliandra eriophylla, Prosopis juliflora, and Zinnia pumila. Common succulents include Opuntia (cholla), Agave palmeri, and A. parryi.

Grasses tend to be more common and prominent eastward, but most are found throughout the area. Species of Bouteloua are the most common. Aristida and Muhlenbergia are also well represented as is Tridens pulchellus.

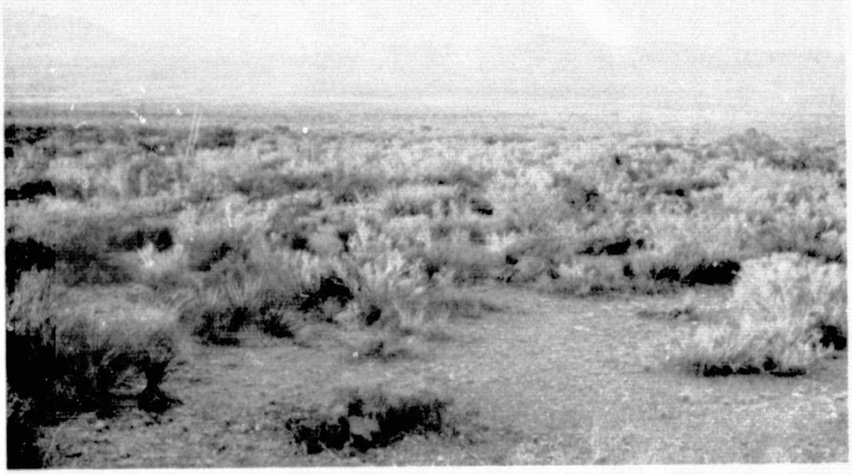


Figure 20. Mortonia scabrella with Rhus choriophylla.

Representatives of this type usually have a "shrub-scrub" physiognomy.

Mortonia scabrella and Rhus choriophylla when found in combination are the only species that need be recognized to identify this vegetation type. In most stands, Mortonia has the highest prominence value (5), yielding a shrub aspect. Other shrubs are normally not abundant, but may include Cercocarpus breviflorus, Fouquieria splendens, and Aloysia wrightii. A shrubby Quercus and Pinus cembroides may also be present.

Leaf succulents are common to most stands and most frequently exhibit mid-prominence values. The more common species are Nolina microcarpa, Dasylirion wheeleri, and Yucca.

Grasses are most commonly represented by Aristida and Bouteloua. In some stands, grass prominence values rank high enough to give a shrub-grass physiognomy.

This vegetation type is well defined, occurs in limited habitats, and is found adjacent to and is closely related to the other Mortonia type, "Mortonia scabrella (without Rhus choriophylla)."

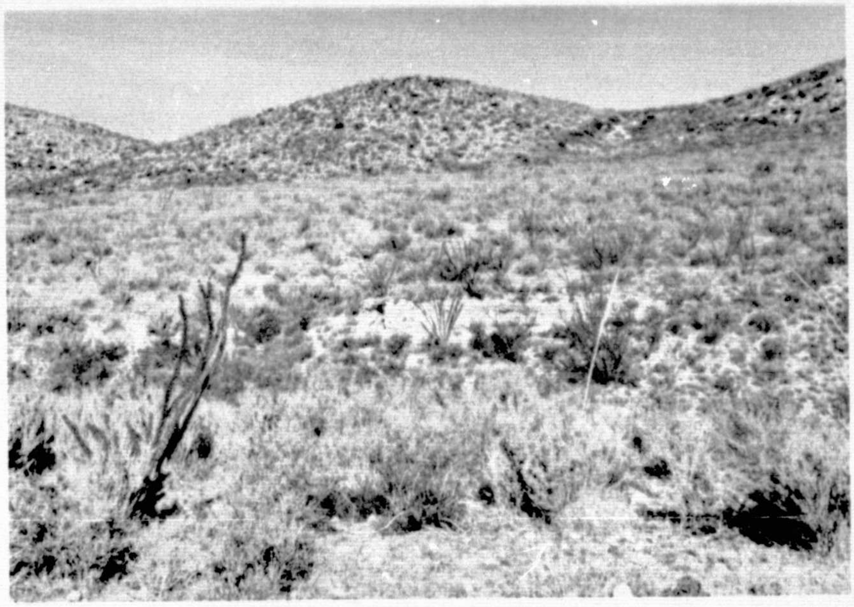


Figure 21. Mortonia scabrella (without Rhus choriophylla). (V. T. 14 = Mosc)

Stands of this vegetation type have a "shrub-scrub" physiognomy.

The vegetation of this type is identified by the presence of Mortonia scabrella. However, the absence of Rhus choriophylla is also required for complete characterization.

In most stands, Mortonia has the highest prominence value (5), but several other shrub species can also be present, and quite abundant (prominence values of 5-4). The more common species are Fouquieria splendens, Parthenium incanum, Zinnia pumila, Larrea tridentata, Acacia vernicosa, Calliandra eriophylla, and Rhus microphylla.

Succulents are also common, especially Dasylirion wheeleri and Nolina microcarpa. Agave, Opuntia (prickly pear), and Yucca occur, but in fewer stands.

Grasses are abundant, especially species of Bouteloua, Aristida, and Tridens pulchellus. Although grass prominence values can be high, stands normally maintain a shrub physiognomy.

This type is well defined and occurs in close proximity to a related and similar appearing type, "Mortonia scabrella with Rhus choriophylla."

Figure 22. Prosopis juliflora and Bouteloua, (without Nolina microcarpa, Quercus, and Juniperus). (V. T. 15 = PrBo)

The physiognomy of the type is best expressed as an intergradation between a "shrub-scrub" and "herbaceous" type.

Grasses and Prosopis juliflora combine to create the herbaceous or grass-shrub physiognomy of the type. Prosopis normally does not have high prominence values (mostly 3) and other tall shrubs and trees are nearly absent. The succulent, Nolina microcarpa, is also absent in the type. Two low shrubs, Haplopappus tenuisectus and Calliandra eriophylla, are also absent.

Mimosa biuncifera is occasionally present and sometimes has high prominence values, but because of its stature, it does not interrupt the physiognomy. The only succulent which is fairly common is Yucca elata. Opuntia (prickly pear and cholla) when present has low prominence values (2-1).

Species of Bouteloua generally rank highest in prominence value among the stands of the type, with B. eriopoda, B. curtipendula, B. gracilis, and B. hirsuta being the most prominent and common. Aristida is normally present and sometimes ranks highest. Occasionally, stands can have unusually high prominence values for Eragrostis, Hilaria belangeri, and Andropogon barbinodis.

There appear to be several types to which this vegetation type is related. They include the grasslands without shrubs as well as other Prosopis/Bouteloua types.

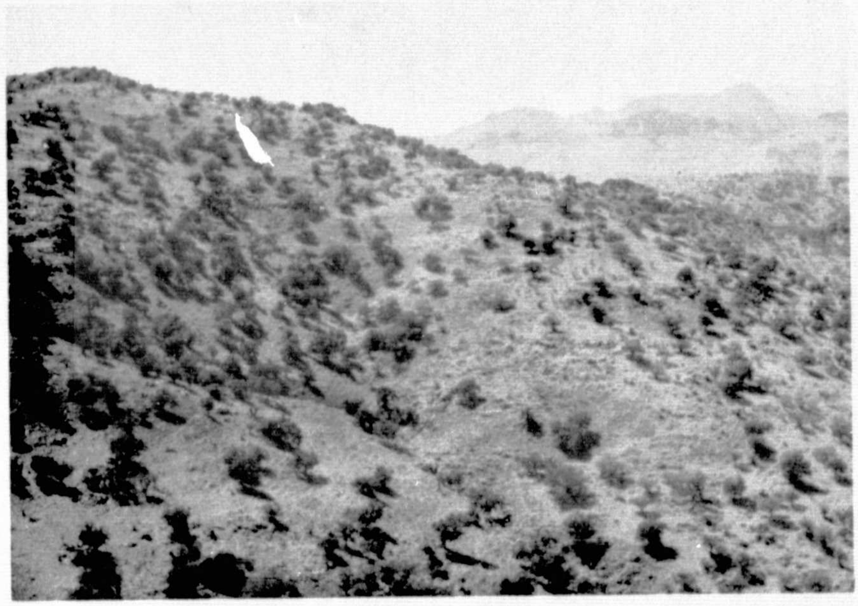


Figure 23. Prosopis juliflora and Bouteloua with Quercus (usually Q. oblongifolia) and/or Juniperus deppeana. (V. T. 16 = PrBQ)

The vegetation type is represented by a variety of physiognomic forms, primarily undifferentiated intergradations. The most consistent structural characteristic is the presence of a well developed herbaceous layer.

The character species of the type are Prosopis juliflora, Bouteloua, and Quercus oblongifolia or Juniperus deppeana. Prominence values vary greatly for these species from stand to stand. However, in most stands, one species is either prominent or at least one shares prominence with other species.

In addition to the Quercus mentioned, Q. emoryi may be present. Mimosa biuncifera and/or M. dysocarpa are often present, and the genus represents the only shrub form other than Prosopis that is commonly present.

Leaf succulents (Agave palmeri and/or A. parryi, Dasylirion wheeleri, Nolina microcarpa, and Yucca) are frequently present as are stem succulents of the genus Opuntia (cholla and prickly pear). Agave schottii is seldom present.

There are several other vegetation types involving Prosopis and Bouteloua to which this type appears closely related. The presence of an overstory of Quercus and/or Juniperus is the most distinguishing characteristic. There are, however, less consistent characteristics which support the distinction. These other characteristics consist of the less commonly associated plant species which are more common in the forest and wood physiognomic type.

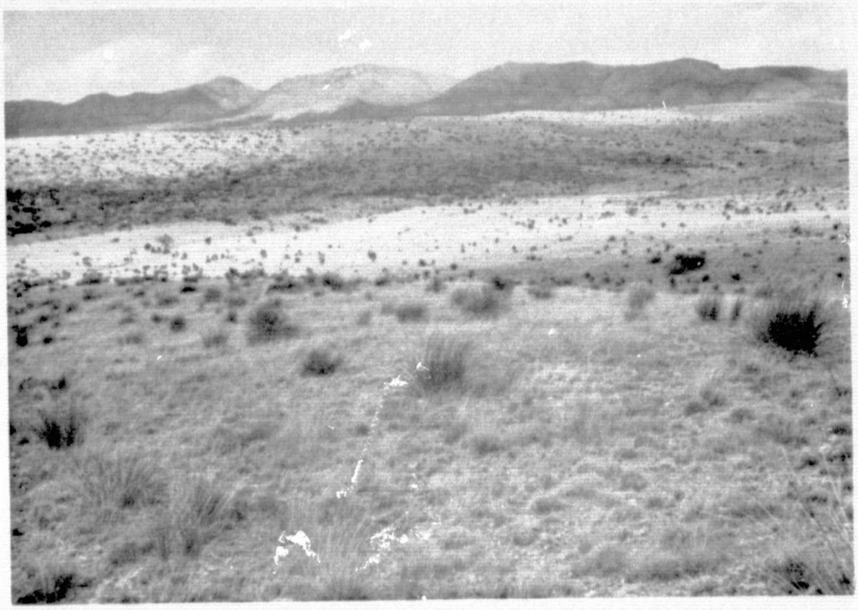


Figure 24. Bouteloua, Aristida, and Nolina microcarpa, (without Calliandra eriophylla). (V. T. 17 = BoNo)

Even though a few tall shrubs may be present in the type, the physiognomy is "herbaceous." The vegetation subclass is "sodgrass and mixed sodgrass-bunchgrass steppe and prairie."

The type is characterized primarily by the presence of Nolina microcarpa in either the most prominent position or coprominent with grasses. Thus, although some shrubs can be present, they do not contribute greatly to the aspect because of their rather low abundance. The more common shrub species are Prosopis juliflora, Ephedra trifurca, Baccharis pteronioides, and Rhus microphylla. Calliandra eriophylla is absent.

Succulents other than Nolina which are commonly present include Yucca baccata, Y. elata, and Dasylirion wheeleri.

Bouteloua curtipendula, B. hirsuta, and B. eriopoda, in that order, tend to be the most common and abundant grama grasses. As a group, perennial species of Aristida tends to rank second. Although several other grass species can be present, they are seldom abundant.

This vegetation type is similar to other herbaceous types which have an abundance of Bouteloua. The differentiating features are primarily based on associated shrubs, trees, or succulents.

Figure 25. Bouteloua and Aristida (without large shrubs, Nolina microcarpa, Yucca, and Calliandra eriophylla). (V. T. 18 = Bout)

This "herbaceous" vegetation type fits into the class of "sodgrass and mixed sodgrass-bunchgrass steppe and prairie."

Perennial grasses of Bouteloua and Aristida combine to give this type its herbaceous aspect. However, presence of the grasses alone is not sufficient to separate the type from others. In addition to the general observation that there are nearly no large shrubs or succulents, it is important to notice that there is an absence or near absence of Prosopis juliflora, Calliandra eriophylla, Haplopappus tenuisectus, Nolina microcarpa, and Zinnia pumila in addition to species of the genera Acacia, Agave, and Yucca. Small shrubs are often present in high prominence, but because of their low stature they do not interrupt the grass aspect of the type. Mimosa biuncifera and M. dysocarpa are the small shrub species most often present.

As a group, perennial Bouteloua usually has the highest prominence value (5). The most common species are B. curtipendula, B. gracilis, B. chondrosioides, and B. eriopoda. Perennial Aristida is present in nearly all stands, but highly variable in prominence value. Although other perennial grass species can be occasionally abundant, the only one consistently present is Andropogon barbinodis.

Several types are similar to this one with the major distinguishing features being the presence or absence of associated shrubs.

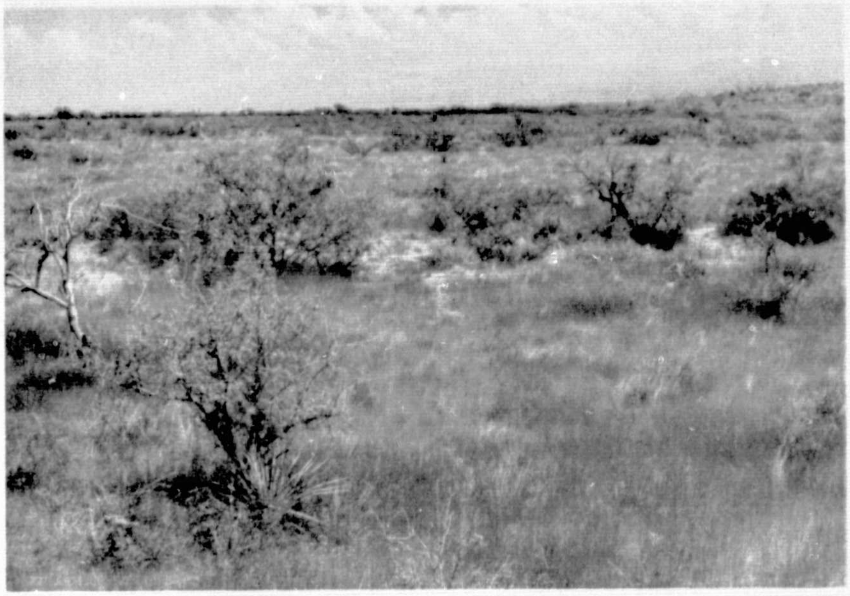


Figure 26. Calliandra eriophylla and Bouteloua with any or all of Ephedra trifurca, Yucca baccata, Y. elata, and Prosopis juliflora, (without Acacia constricta). (V. T. 19 = BoYu)

The physiognomy of the type fluctuates between "herbaceous" types and an intergradation of "scattered tall shrubs over herbs."

As in some other types, Calliandra eriophylla and Bouteloua are present and substantially contribute to the herbaceous aspect of the type, even though Calliandra is not herbaceous. Prosopis juliflora is the most common tall shrub species, and, when present, it too influences the aspect of the type. Haplopappus tenuisectus and Ephedra trifurca are important in type identification. Noting the absence of Acacia constricta, and near absence of Acacia greggii, Fouquieria splendens, Mimosa biuncifera, and M. dysocarpa is important for the same reason. The latter group, when present have low prominence values.

Yucca elata and Y. baccata are important succulents. The near absence of Ferocactus wislizenii is also characteristic. Several other stem and leaf succulents occur in the type.

Grasses abound and usually have high prominence values (5). The genus, Bouteloua, has many species represented including B. curtipendula, B. eriopoda, and B. rothrockii. Aristida and Andropogon rank next to Bouteloua in frequency of occurrence and prominence followed closely by Muhlenbergia and Panicum.

In addition to being related to other herbaceous types, this vegetation type is similar to the others with Calliandra, especially, "Calliandra eriophylla usually with any or all of Fouquieria splendens, Mimosa biuncifera, M. dysocarpa, and Ferocactus wislizenii, (without Acacia constricta)."

Figure 27. Prosopis juliflora bosque.

Prosopis juliflora is the most prominent species along some major drainageways, attaining tree-like proportions of thirty feet near the primary river channels and becoming smaller on the floodplains. However, the stature of Prosopis on the floodplains qualifies the type as a "woods." Although associated shrubs and understory vegetation may be present in the bosque, the aspect is completely dominated by Prosopis.

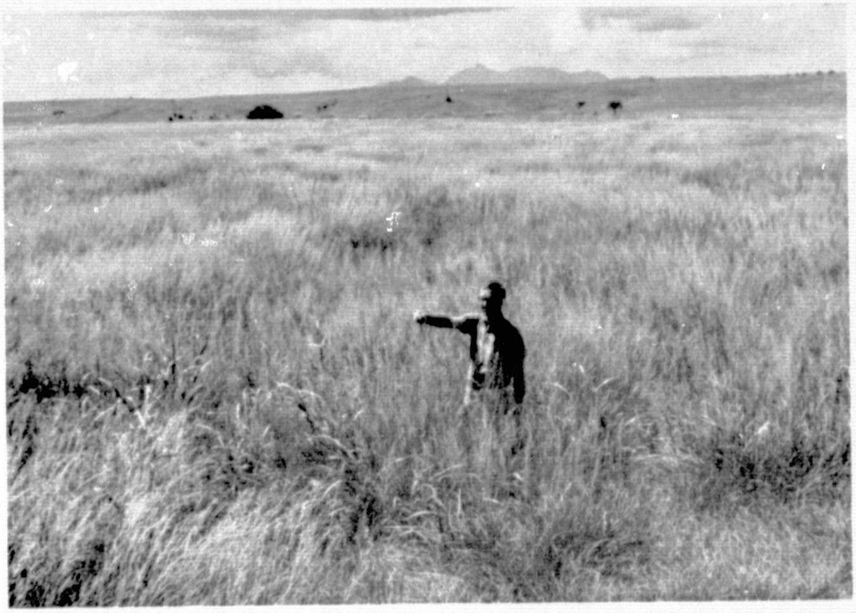


Figure 28. Sporobolus wrightii often with Prosopis juliflora. (V. T. 21 = Spwr)

When Prosopis is present, the physiognomy of the type is an intergradation of "scattered tall shrubs over herbs." When absent, the physiognomy is "herbaceous."

Sporobolus wrightii holds the most prominent or coprominent position in this vegetation type which is confined to drainageways. When coprominent, the other species is Prosopis juliflora. Thus, depending on the presence or absence of Prosopis, the type has a grassland or a shrub-grass aspect. Few other shrubs contribute consistently to the type, and succulents, when present, are sparse. In addition to Sporobolus, Aristida and Bouteloua are common grass components.

Figure 29. Hilaria mutica and Prosopis juliflora. (V. T. 22 = Himu)

The physiognomic characteristic for most stands of the type is an intergradation of "scattered tall shrubs over herbs."

Hilaria mutica occurs as the prominent or coprominent species with Prosopis juliflora and usually occurs in and along drainageways. Although several other species can be present in the type, these two completely dominate the aspect. Some of the more common shrub species that may occur, but generally with low prominence values are Acacia constricta, Haplopappus tenuisectus, Ephedra trifurca, and Zinnia pumila. A few succulents can also be present, especially Yucca and Opuntia (cholla and prickly pear). The most common associated grass genera are Bouteloua, Aristida, Muhlenbergia, and Eragrostis.

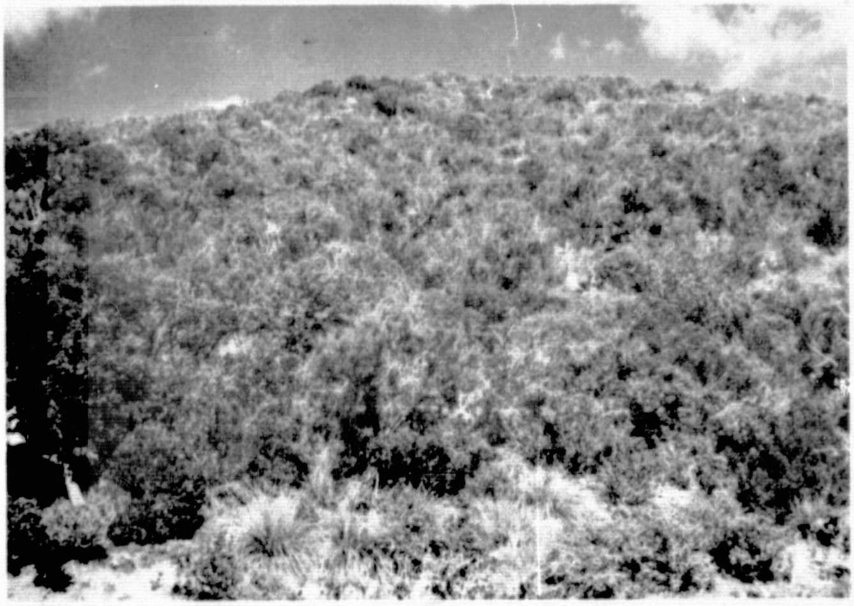


Figure 30. Cercocarpus breviflorus with Juniperus deppeana and/or Pinus cembroides and usually with Quercus. (V. T. 23 = Cebr)

The physiognomic expression of this type is quite variable. Stands appear as "forest and woods," "shrub-scrub," and "intergrades" of several types.

An overstory is always present although it sometimes consists of widely scattered trees over tall shrubs and may be quite inconspicuous The more common oaks are Quercus arizonica, Q. emoryi, and Q. reticulata. Juniperus deppeana is usually present with Pinus cembroides and is nearly always present when the pine is absent. The character species, Cercocarpus breviflorus, usually has a prominence value of 5-3.

Garrya wrightii, Rhus choriophylla, and R. trilobata are frequently associated shrub species. Species of Ceanothus, in addition to Cercocarpus breviflorus, may also be present.

Leaf succulents are always present; Nolina microcarpa and Yucca schottii are the most consistent. When present, Dasylirion wheeleri and Pinus cembroides usually occur together in this type. Agave are only occasionally present.

Perennial grasses are always present; Bouteloua curtipendula is the most common.

Figure 31. Quercus, Arctostaphylos pungens, Pinus cembroides, and Juniperus deppeana, (without Mimosa biuncifera). (V. T. 24 = QuAr)

The physiognomy of the type is generally that of "woods," but some stands may have a "shrub-scrub" or "intergrade" aspect of "scattered trees over shrubs."

The trees of the type include Pinus cembroides with mid-to low prominence values and Juniperus deppeana with mid-prominence values. Quercus emoryi and Q. arizonica are the most common oak species and they usually have mid-to high prominence values. The characteristic shrub of the type is Arctostaphylos pungens. It has mid-to high prominence values (3-5). Other shrub species are only occasionally present and usually do not have high prominence values. For purposes of type recognition, the absence of Mimosa biuncifera need be noted.

Two leaf succulents are common to the type. They are Nolina microcarpa which has mid-prominence values and Yucca schottii which usually has low prominence values. Agave and Dasylirion wheeleri are only occasionally present. Stem succulents are uncommon.

Perennial grasses are usually present although the herbaceous layer is seldom strongly expressed.

Figure 32. Quercus and Arctostaphylos pungens usually with Mimosa biuncifera, (without Pinus cembroides). (V. T. 25 = QAMi)

This vegetation type is expressed in several physiognomic forms including "intergrades" (both scattered tree and shrub over grass), "shrub-scrub," and "woods."

The most characteristic oak is Quercus emoryi (prominence value mostly 5-3) and it is almost always present. Arctostaphylos pungens is always present; most often with mid-prominence values. Mimosa biuncifera and/or M. dysocarpa are also normally present and contribute to the characterization of the type even though they have low prominence values. The absence of Pinus cembroides further distinguishes this type.

Juniperus deppeana occurs frequently with mid-prominence values in several stands of the type and J. monosperma in a few. Two additional oaks are not frequently present, but they can be conspicuous. They are Quercus oblongifolia and Q. arizonica. Several shrub species can also be present, but none of them are consistent and they seldom have high prominence values.

Leaf succulents are usually present with mid-to low prominence values. Dasylirion wheeleri and Nolina microcarpa are most common. Agave species including A. schottii are also common. Yucca schottii is seldom present.

Perennial grasses are usually present, frequently in high prominence. Bouteloua curtipendula and species of Andropogon, Aristida, and Muhlenbergia are the most conspicuous.

Figure 33. Cowania mexicana usually with Juniperus. (V. T. 26 = Come)

This type usually has the appearance of an "intergrade" type of "scattered tall shrub over herbs" or "evergreen sclerophyll shrub" ("shrub-scrub").

Cowania mexicana is the species which determines the character of this vegetation type. In most cases Cowania ranks high in prominence value (5-4).

Trees are common to the type but seldom with high prominence values. Juniperus and Quercus are about equally common with both genera occasionally represented in a stand.

In addition to Cowania, several shrubs contribute to the type mostly with mid-to low prominence values. The more common are Cercocarpus breviflorus, Mimosa, and Rhus choriophylla.

Succulents are a very common component, especially Agave (other than A. schottii), Dasylirion wheeleri, and Nolina microcarpa.

The herbaceous layer is generally well developed and usually includes Andropogon barbinodis, Aristida, Bouteloua curtipendula, Hilaria belangeri, and Muhlenbergia.

This type is not taxonomically closely related to other types in the study area.

Figure 34. Quercus and Mimosa (without Arctostaphylos pungens and Cercocarpus breviflorus). (V. T. 27 = QuMi)

Representatives of this type are either "woods" or "intergrades" having "scattered trees over an herbaceous layer." In either case, the herbaceous layer is well developed.

The oak, Quercus emoryi, is the most characteristic tree species of the type, being almost always present and having a high prominence value (5-4). Mimosa biuncifera is the usual Mimosa present and it has widely varying prominence values. To distinguish this from other types, the absence of Arctostaphylos pungens and Cercocarpus breviflorus is noteworthy.

Other tree species which are common include Quercus arizonica and Q. oblongifolia, although evidence suggests that they are not found together. Juniperus deppeana and J. monosperma may also be present.

Shrubs, other than Mimosa, are not an important component of the type. Leaf succulents, however, are common in most stands. The more common succulents are Agave (other than A. schottii), Dasylirion wheeleri, Nolina microcarpa, and Yucca schottii.

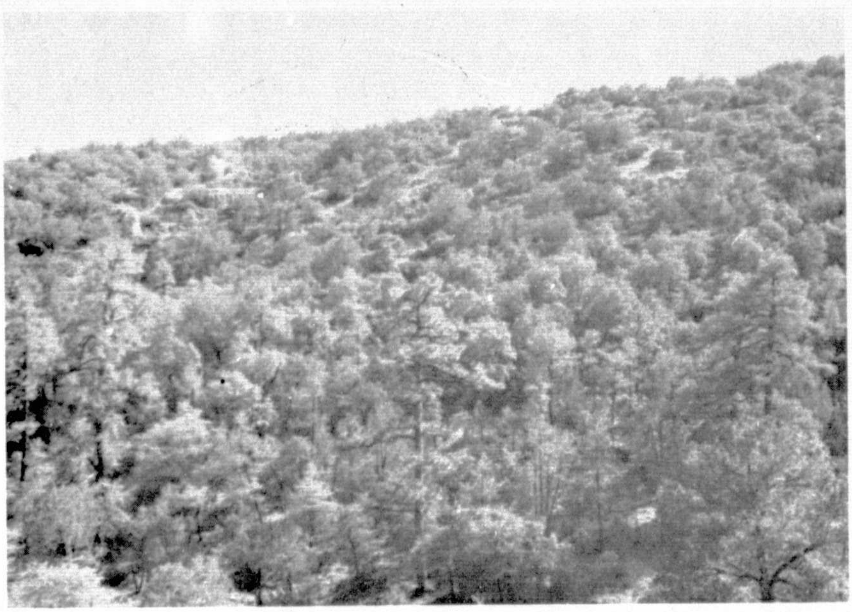


Figure 35. Pinus, often with Pseudotsuga menziesii, Quercus hypoleucoides, and Q. gambelii.

Physiognomically, representatives of this type are members of "mixed forests of needleleaf-broadleaf."

Several species of pine may be present in a stand of this broad type, although pines do not have to be most prominent. Either Pinus ponderosa or Quercus hypoleucoides is usually the most prominent species. Other species which may be most prominent or coprominent are Pinus engelmannii, P. strobiformis, Quercus arizonica, Q. emoryi, and Q. reticulata. Other common tree species in the type are Pinus cembroides, P. leiophylla, Pseudotsuga menziesii, Juniperus deppeana, and Quercus gambelii. Scattered shrubs and grasses, especially Muhlenbergia, can be common in the understory.

This broadly described typr is found in the highest elevations of the study area and on a site-to-site basis may be related to any of the generally lower elevation vegetation types which commonly contain oak and juniper. Included within this type may be inclusions of vegetation types which contain the species Populus tremuloides, Robinia neomexicana, and species commonly found in mountain meadows.

Figure 36. _Populus fremontii_, _Fraxinus velutina_, _Platanus wrightii_, and/or _Chilopsis linearis_. (V. T. 29 = Ripa)

Stands of the type normally have a "forest and woods" physiognomy. The type is riparian. The more common trees are _Populus fremontii_, _Fraxinus velutina_, _Platanus wrightii_, and _Chilopsis linearis_. They do not, however, necessarily occur together as the type is broadly defined. Several species of oak (_Quercus arizonica_, _Q. emoryi_, _Q. hypoleucoides_, and _Q. reticulata_) and _Juniperus deppeana_ may also be found in the type. Shrub and tree forms of _Prosopis juliflora_ may also be present in the type. The type is unique to riparian situations and is not closely associated with other types described.

Figure 37. Quercus and Nolina microcarpa (without Cercocarpus breviflorus, Arctostaphylos pungens, and Mimosa biuncifera). (V. T. 30 = QuNo)

The physiognomy of this vegetation type is usually that of "woods" or occasionally, "intergrades."

Oaks are the most conspicuous genera of the type and are generally prominent (5-4). Nolina microcarpa is the other characteristic species; it has a wide range of prominence values. Cercocarpus breviflorus, Arctostaphylos pungens, and Mimosa biuncifera are never present in stands of this type.

The most common oak species is Quercus emoryi. Less common oak species include Q. arizonica, Q. hypoleucoides, and Q. reticulata. Juniperus deppeana is occasionally present but normally with mid-to low prominence values.

Shrubs may be present, but usually with low prominence values and number of species.

Other than Nolina, Yucca schottii is the only other leaf succulent consistently present, although occasional species of Agave do occur Stem succulents are not common.

The herbaceous layer is usually well developed. The most common genera are Andropogon, Aristida, Bouteloua, Eragrostis, and Muhlenbergia.

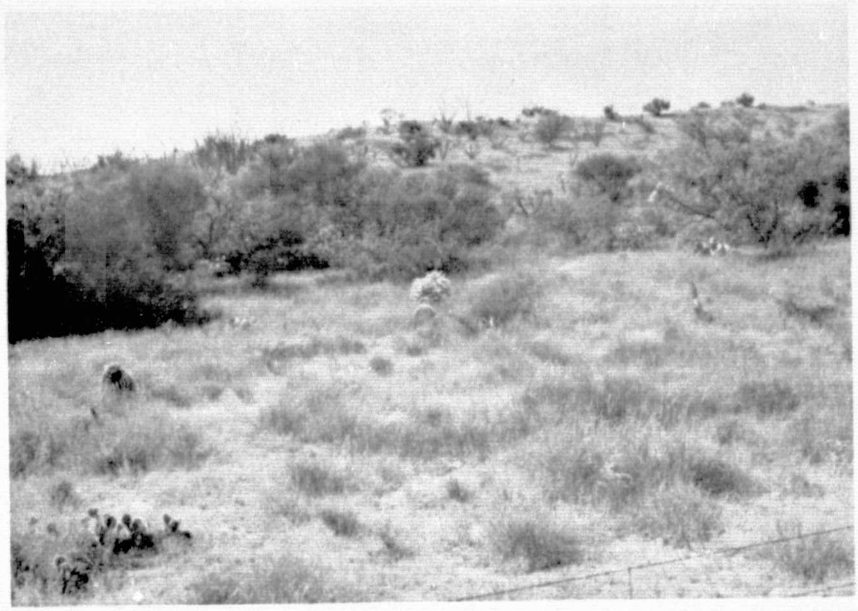


Figure 38. Calliandra eriophylla and Bouteloua usually with any or all of Fouquieria splendens, Acacia greggii, Mimosa biuncifera, M. dysocarpa, and Ferocactus wislizenii, (without Acacia constricta). (V. T. 31 = BoFo)

The structural characteristic of the type is primarily an intergradation of "scattered tall shrubs over herbs."

This vegetation type tends to be three-layered with tall shrubs, low shrubs, and grasses all high in prominence. Calliandra eriophylla is always present in the type in widely fluctuating prominence (5-1). The most conspicuous shrub is normally Prosopis juliflora which is usually present with mid-to high prominence values. Acacia greggii, Fouquieria splendens, Haplopappus tenuisectus, Mimosa biuncifera, and M. dysocarpa are present in a number of stands with mid-to low prominence values. Acacia constricta is not a component of the type. Relatively few other shrubs are found in the type.

Some succulents are represented in rather low prominence in the type. One, Ferocactus wislizenii, is fairly common and is useful in distinguishing this type from a similar one which also contains Calliandra.

Of the grasses, Bouteloua is best represented, often with high prominence values (5-4). B. curtipendula is the most common grass species. The genera, Aristida and Andropogon, are also well represented in the type.

The other vegetation types containing Calliandra can be considered to be similar to this type, especially "Calliandra eriophylla and Bouteloua with any or all of Ephedra trifurca, Yucca baccata, Y. elata, and Prosopis juliflora, (without Acacia constricta)."

individual plant species and terrain variables. The other involved the relationships between vegetation types and terrain variables.

One of the methods used in both analyses involved the construction of graphs and tables showing the distribution of the individual species with regard to the separate terrain variables. Other tables and graphs illustrated the manner in which vegetation types were arranged with respect to one another according to values of specified terrain variables. The interpretation and assessment of the relationships shown on those charts and graphs constituted one method in the data analysis.

Another method of data analysis involved the use of stepwise discriminant analysis. Stepwise discriminant analysis was used because it could determine the differences among groups of individual terrain variables in terms of species observed as occurring with them, the individual species which could best discriminate groups of individual terrain variables, the terrain variables which could best discriminate the vegetation types, and the differences among vegetation types according to their associated terrain variables.

The use of stepwise discriminant analysis in plant ecological studies is not new. Segura-Bustamente (1970), in a study on the ecology of bitterbrush (Purshia tridentata) in Silverlake Deer Winter Range, Oregon used stepwise discriminant analysis to infer certain physiographic and soil characteristics from a knowledge of

vegetation units. Garcia-Moya (1972) in a study on the vegetation classification of the Tombstone, Arizona, vicinity, used stepwise discriminant analysis to test the validity of the character and differential species as indicators for his vegetation units. Pyott (1972) used stepwise discriminant analysis "to evaluate vegetation classification results according to the principles of the Braun-Blanquet system" in eastern Oregon. He also used stepwise discriminant analysis "in determining the degree of correlation of environmental variables with vegetation pattern". He found in this study that environmental data, site variables, and soil physical and chemical variables were equally prominent as the first discriminants entered (Pyott, 1972). Norris and Barkham (1970) used multiple-discriminant analysis in a study of English Cotswold beechwoods. They identified thirteen woodland communities, "woods". From their analysis, they found that the first two axes generated by multiple-discriminant analysis separated the woods according to soil texture variation. The third axis seemed to relate to management practice. They concluded with the observation that multiple-discriminant analysis was useful in displaying differences between groups of sites.

A stepwise discriminant analysis program is provided in the Biomedical program (BMDO7M; Sampson, 1968) and performs a multiple-discriminant analysis in a stepwise manner (Appendix II

gives the general characteristics of the program used in this thesis). At each step in the program, a variable is entered into the set of discriminating variables (for example, terrain variables). The variable entered is selected if it has the largest F value. This is the same as the variable which gives the greatest decrease in the ratio of within to total generalized variances. A variable is deleted if its F value becomes too low (Sampson, 1968). This never happened in the analyses conducted. The program also computes canonical correlations and coefficients for canonical correlations. This is important as the program includes the plotting of the first two canonical variables to give an optimal two-dimentional picture of the dispersion among observations (this is referred to as a "scatter diagram" in the Results and Discussion chapter). Each canonical variate is a function of all the original variables. In this study, the only use of the canonical variables produced by the program was the production of the above-mentioned two-dimensional picture of the dispersion of observations on the basis of the variables employed.

The program also produces a classification matrix of the groups. Observations are placed into a particular program-derived group on the basis of the values of the set of variables noted for the observation (field sample site). For example, one could consider vegetation types as groups and terrain variables as "variables". The classification matrix presents floristically-defined vegetation

types (groups) and terrain variable-defined vegetation types (groups) to define the matrix. A field site (or observation) identified as a certain floristically-defined vegetation type is then placed in a terrain variable-defined vegetation type. Often the selected terrain variable-defined vegetation type is different from the floristically-defined vegetation type to which the observation had originally been assigned. A schematic Venn diagram (Figure 39) can be used to aid the reader in understanding how sets of terrain variables are better correlated with one vegetation type than with another. Two hypothetical vegetation types, A and B, are used in the illustration. An accurate illustration depicting the interaction of all twenty-five vegetation types would require a graphic portrayal of twenty-five dimensions. The scatter diagram produced by the program is essentially a projection of that twenty-five dimensional diagram onto a two-dimensional surface (see Figure 59). In the Venn diagram (Figure 39) are two vegetation types, A and B, which have been restructured into program-derived terrain variable-defined vegetation classes. The set of terrain variables, A, includes all possible combinations of terrain variables which could theoretically exist for the hypothetical vegetation type A. The set of terrain variables, B, includes all possible combinations of terrain variables which could theoretically exist for the hypothetical vegetation type B. The overlap between the two sets means that for that particular subset of

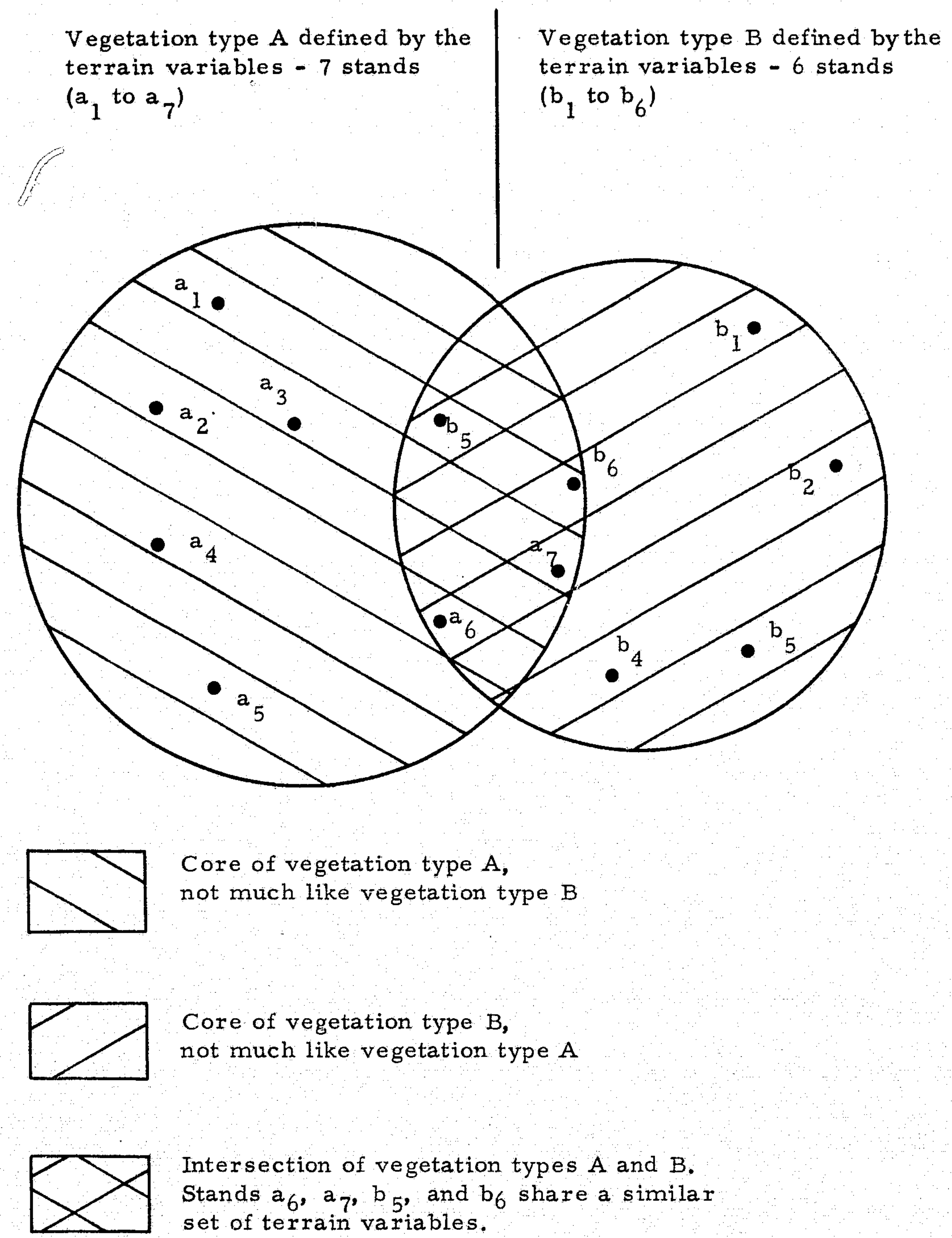


Figure 39. A schematic Venn diagram of two hypothetical vegetation types according to their sets of terrain variables.

terrain variables, two vegetation types can theoretically exist. In Figure 39, vegetation type A is considered to have seven stands, while type B has six stands. Stand A_1 has a set of terrain variables that is most like the typical set of A terrain variables. It is not very much like type B. Stand A_3 is on the very fringe of terrain variables that can have a vegetation type A. Its set of terrain variables is actually more like the "typical" B set.

Stepwise discriminant analyses discussed in this thesis which used individual plant species and individual terrain variables can be understood in a similar context, with respect to their classification matrices, as in the above example.

V. RESULTS AND DISCUSSION

As indicated previously, the research involves two fundamental types of relationship between vegetation and terrain variables: relationships between individual species and terrain variables, and relationships between vegetation types and terrain variables. Toward achieving an understanding of those relationships, solutions and partial solutions were obtained of ancillary objectives. Those objectives included supplying background information for an ecologically based classification of biotic resources in an arid and semiarid environment and in assessing the accuracy of photo-interpretation in recognizing the vegetational pattern within the study area.

Another ancillary objective involved in studying relationships between individual species and terrain variables was to determine indicator species which are species that indicate not only specific parent materials, but also other terrain variables.

Relationships Between Individual Species and Terrain Variables

Results of analyses performed indicate two basic sets of information. One was the determination of the amplitude or range of physiographic conditions over which each species is found. The other involved the degree to which particular species discriminate groups or classes of terrain variables.

Of the 160 species in the sample sites, 106 had frequencies of five or more. Those 106 species were then used in the computer analyses described earlier. Species for analysis were subsequently reduced to 41 on the basis of frequency and on preliminary computer analyses of the 106 species. These 41 species will be discussed in this section (Table 1).

Elevation

Elevation amplitudes for the species reveal that some species occur over a wide range of elevation. Other species appear to be narrowly restricted. Most, however, are limited or restricted to moderate ranges of elevation. Figure 40 illustrates the distribution of species by elevation.

The elevation ranges of the species may be considered to fall into approximately seven groups or categories. Table 2 illustrates the distribution tendencies of species among elevation groups; an interpretation follows. Species that occur almost exclusively in the low elevations, that is, under 3,800 feet include *Opuntia fulgida*, *Cercidium floridum*, *Cercidium microphyllum*, and *Cereus giganteus*.

Species that occur predominantly in the low and middle elevations include *Acacia constricta*, *Condalia lycioides*, *Ferocactus wislizenii*, *Haplopappus tenuisectus*, *Larrea tridentata*, and *Zinnia pumila*.

Table 1. Plant species used in the data analyses. (For complete list of plant species see Appendix I). Scientific names are from Kearney and Peebles (1964) and Benson (1969). Common names are from Benson (1969), Benson and Darrow (1954), and Kearney and Peebles (1964).

	Alpha title	Scientific name	Common name
Trees	Jude	Juniperus deppeana	Alligator juniper
	Jumo	J. monosperma	One-seed juniper
	Pice	Pinus cembroides	Mexican Pinyon
	Quar	Quercus arizonica	Arizona Oak
	Quem	Q. emoryi	Emory oak
	Quob	Q. oblongifolia	Mexican blue oak
Shrubs	Acco	Acacia constricta	Whitethorn
	Acve	A. vernicosa	Mescat Acacia
	Alwr	Aloysia wrightii	Wright's lippia
	Arpu	Arctostaphylos pungens	Manzanita
	Caer	Calliandra eriophylla	Fairy duster
	Cefl	Cercidium floridum	Blue palo verde
	Cemi	C. microphyllum	Foothill palo verde
	Cebr	Cercocarpus breviflorus	Mountain mahogany
	Coly	Condalia lycioides	Gray-thorn
	Come	Cowania mexicana	Cliffrose, Quinine-bush
	Flce	Flourensia cernua	Tarbush
	Fosp	Fouquieria splendens	Ocotillo
	Hate	Haplopappus tenuisectus	Burroweed
	Latr	Larrea tridentata	Creosotebush
	Mibi	Mimosa biuncifera	Wait-a-minute bush
	Midy	M. dysocarpa	Velvet-pod Mimosa
	Mosc	Mortonia scabrella	Sandpaper bush
	Pain	Parthenium incanum	Mariola
	Prju	Prosopis juliflora	Mesquite
	Rhch	Rhus choriophylla	Woodland sumac
	Zipu	Zinnia pumila	Desert zinnia
Leaf Succulents	Agpa	Agave parryi	Mescal
		A. palmeri	Mescal

Table 1. Continued.

	Alpha title	Scientific name	Common name
Leaf Succulents	Agsc	A. schottii	Amole
	Dawh	Dasylirion wheeleri	Sotol
	Nomi	Nolina microcarpa	Beargrass (Sacahuista)
	Yuel	Yucca elata	Soaptree yucca
Stem Succulents	Cegi	Cereus giganteus	Saguaro
	Fewi	Ferocactus wislizenii	Barrel cactus
	Opfu	Opuntia fulgida	Jumping cholla
	Opph	O. phaeacantha	Prickly pear
	Opsp	O. spinosior	Cane cholla
Grasses	Bocu	Bouteloua curtipendula	Sideoats grama
	Boro	B. rothrockii	Rothrock grama
	Himu	Hilaria mutica	Tobosa
	Spai	Sporobolus airoides	Alkali sacaton

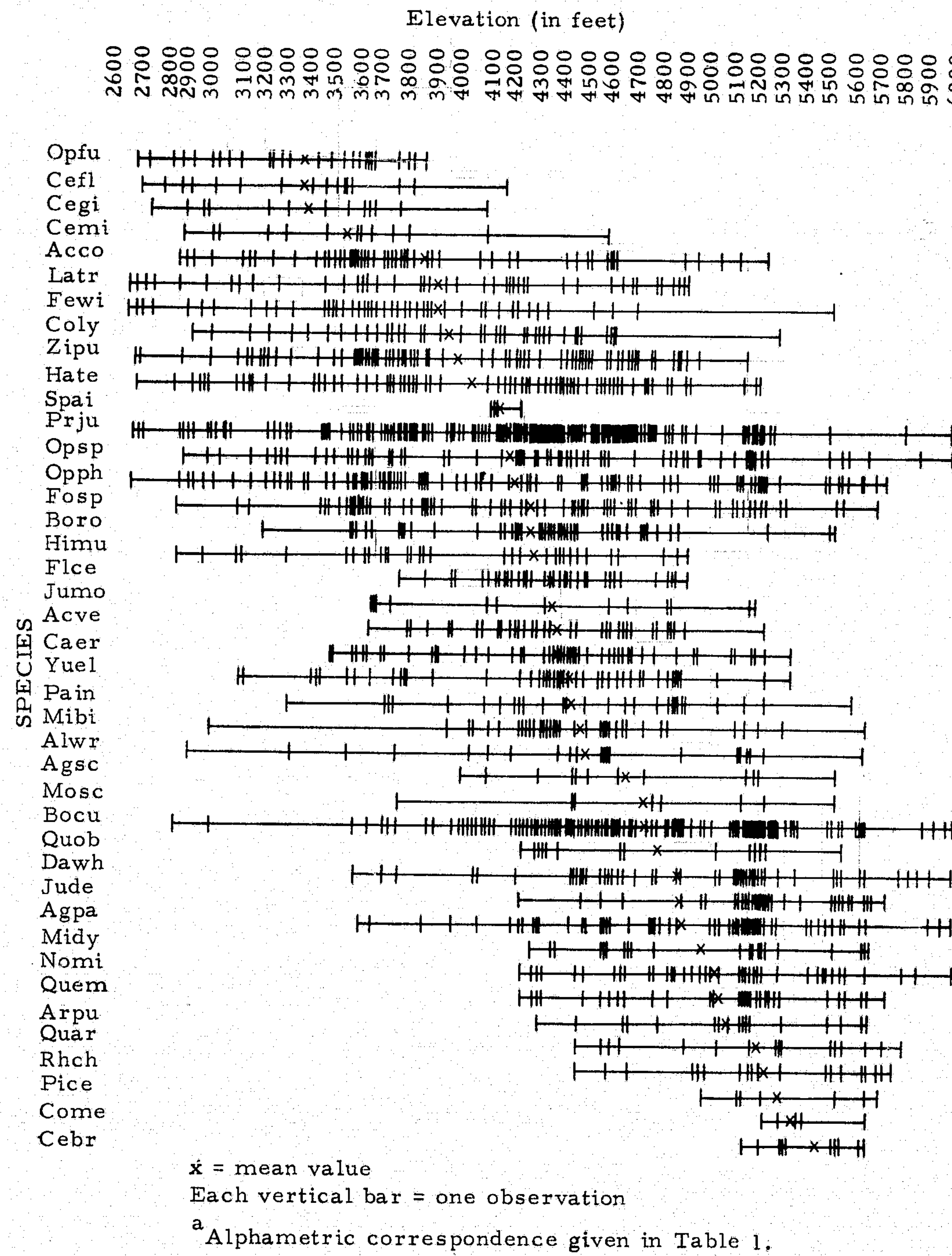


Figure 40. Distribution of species by elevation.

Table 2. Distribution tendencies of species among elevation groups.

Low Elevation

mean: 3,300' to 3,500'
range: primarily 2,700' to 3,800'
Species: Opfu, Cefl, Cemi, Cegi

Low & Middle Elevation

mean: 3,800' to 4,000'
range: primarily 2,700' to 4,900'
Species: Acco, Coly, Fewi, Hate, Latr, Zipu

Middle Elevation

mean: 4,100' to 4,500'
range: primarily 3,500' to 4,900'
Species: Acve, Caer, Flce, Jumo, Mibi, Pain, Yuel, Boro, Himu, Spai

Upper Middle Elevation

mean: 4,600' to 5,000'
range: primarily 4,300' to 5,300'
Species: Agsc, Arpu, Jude, Midy, Mosc, Quem, Quob

Middle & Upper Elevation

mean: 4,700' to 4,900'
range: primarily 4,000' to 5,950'
Species: Agpa, Dawh, Bocu

High Elevation

mean: 5,000' to 5,400'
range: primarily 4,500' to 5,750'
Species: Cebr, Come, Nomi, Pice, Quar, Rhch

Wide Range in Elevation

Species: Alwr, Fosp, Opph, Opsp, Prju

Species that are generally restricted to middle elevations within the study area, that is, between about 3,500 feet and 4,900 feet, include *Acacia vernicosa*, *Calliandra eriophylla*, *Flourensia cernua*, *Juniperus monosperma*, *Mimosa biuncifera*, *Parthenium incanum*, *yucca elata*, *Bouleloua rothrockii*, *Hilaria mutica*, and *Sporobolus aerioides*.

Species that occur in the upper middle elevations, that is generally between 4,300 feet and 5,300 feet, include *Agave schottii*, *Arctostaphylos pungens*, *Juniperus deppeana*, *Mimosa dysocarpa*, *Mortonia scabrella*, *Quercus emoryi*, and *Q. oblongifolia*.

Species that occur predominantly in middle and upper elevations, above 4,000 feet, include *Agave palmeri*, *A. parryi*, *Dasylirion wheeleri*, and *Bouteloua curtipendula*.

Species that occur predominantly in the high elevations of my study area include *Cercocarpus breviflorus*, *Cowania mexicana*, *Nolina microcarpa*, *Pinus cembroides*, *Quercus arizonica*, and *Rhus choriophylla*.

Species that occur throughout the elevation range of my study area include *Aloysia wrightii*, *Fouquieria splendens*, *Opuntia phaeacantha*, *O. spinosior*, and *Prosopis juliflora*.

Predominant life forms among the 41 species at the lower elevations were stem succulents and trees (*Cercidium* spp., for example). In the low and middle elevation category, shrubs became

dominant. Leaf succulents did not occur in the lower elevations. In the middle elevation category, grasses, leaf succulents, shrubs, and one tree species were important life forms. In the upper middle elevation category, shrubs and trees were about evenly split. Shrubs, leaf succulents, and trees were the only important life forms at higher elevations. Finally, stem succulent and shrub life forms ran the gamut of the elevations within my study area.

Elevation _per se_ is only a surrogate of other, more direct, controls on vegetation. Those other controls which correlate well with elevation are precipitation, temperature, and soil moisture. Elevation itself is essentially an indicator of those variables.

Parent materials

Species exhibited a wide range of occurrences on parent materials. Five basic sets of observations can be drawn from the observed frequencies of species on each of the parent materials. Some species are virtually restricted to alluvial parent materials, while others are virtually restricted to non-alluvial parent materials. Some species occur on all parent materials but are noticeably absent from one. Some species favor neither alluvial nor non-alluvial parent materials. Finally, some species occur on all parent materials but are limited by one. Figure 41 illustrates the range in distribution of species according to the types of parent material they were

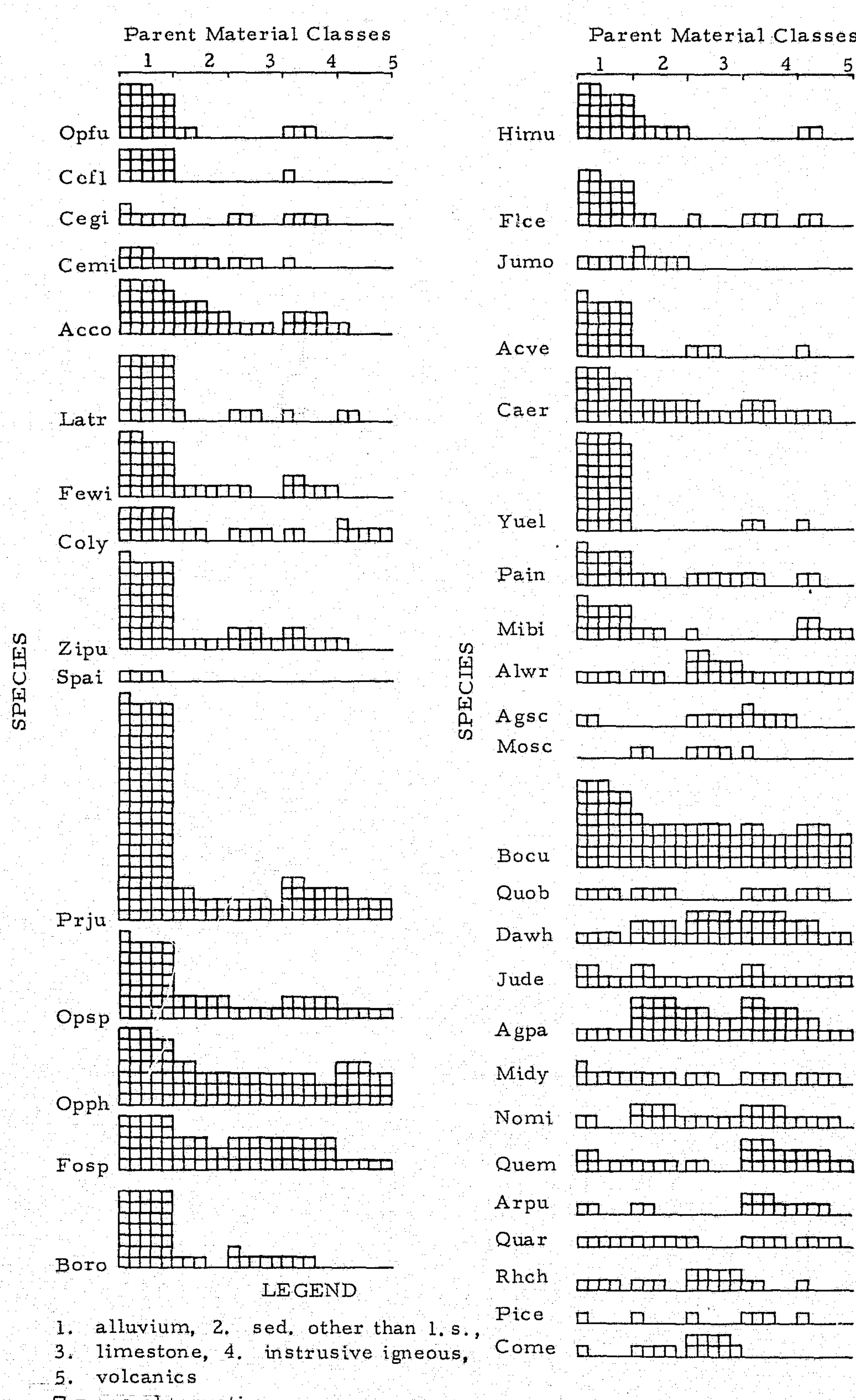


Figure 41. Distribution of species by parent materials.

associated with. Species in that figure are listed in the same sequence as they were listed in Figure 40, the illustration of elevation ranges for species.

Parent material is not uniformly distributed with elevation. At the lowest elevations within the study area, below 3,000 feet, alluvial parent materials comprise nearly all of the area. Above 5,000 feet, however, alluvial parent materials comprise only a small percentage of the area. Thus, it is not a simple task to discern whether or not species are limited to alluvial or non-alluvial parent materials, for example, or to high or low elevations. This should be kept in mind during the following discussion of observations.

The following discussion of observations follows Table 3.

Ten species occur primarily on alluvial parent materials: Acacia vernicosa, Bouteloua rothrockii, Cercidium floridum, Flourensia cernua, Haplopappus tenuisectus, Hilaria mutica, Larrea tridentata, Opuntia fulgida, Sporobolus aerioides, and Yucca elata. Cercidium floridum occurred fifteen times on alluvium and only once on a non-alluvial parent material. Sporobolus aerioides occurred only on alluvial parent materials although it had an observed frequency of only four. Yucca elata, an important component of the grasslands, occurred 49 times on alluvial parent materials and three times on non-alluvial parent materials.

Table 3. Distribution tendencies of species among parent materials.

Species occurring primarily on alluvium:

Acve, Boro, Cefl, Flce, Hate, Himu, Latr, Opfu, Spai, Yuel

Species occurring primarily on non-alluvial parent materials:

Primarily limestone: Alwr, Cebr, Come, Mosc, Rhch

Primarily igneous: Arpu, Pice

Undifferentiated: Agpa, Dawh, Nomi, Opph

Primarily on limestone and igneous parent materials: Agsc

Species occurring on all parent materials but absent from one:

Absent from volcanics: Cegi, Cemi, Fosp

Absent from limestone: Arpu, Quob

Species not favoring either alluvial or non-alluvial parent Materials:

No preference: Bocu, Caer, Coly, Jude, Midy, Opsp, Pain, Prju

Species limited by volcanics:

Acco, Fewi, Zipu

Species limited by limestone:

Mibi, Quar, Quem

Primarily on alluvium and sandstone: Jumo

Of the twelve species which appeared to be restricted or strongly influenced by non-alluvial parent materials, some were also strongly influenced by a single parent material while others occurred on a number of non-alluvial parent materials.

It appears as if limestone is the non-alluvial parent material having the greatest impact upon the occurrence of plant species. Five species occurred primarily on limestone. Aloysia wrightii occurs over a wide range of elevations as well as parent materials, yet it is especially prolific on limestone. Mortonia scabrella has been observed as occurring on igneous and sandstone parent materials but it is often the stand dominant on limestone. Rhus choriophylla, while occurring on all parent materials, is very abundant, in higher elevations, on limestone. Cercocarpus breviflorus and Cowania mexicana also occur primarily on limestone in the higher elevations.

Arctostaphylos pungens and Pinus cembroides occur primarily on igneous parent materials.

Four species occurred on a wide variety of non-alluvial parent materials. They include Agave spp. (not including A. schottii), Dasylirion wheeleri, Nolina microcarpa, and Opuntia phaeacantha. Agave schottii occurs primarily on limestone and igneous parent materials.

Five species were observed as occurring on all of the parent materials except for one. Cereus giganteus, Cercidium microphyllum, and Fouquieria splendens were either greatly limited or were absent only from volcanic parent materials. Arctostaphylos pungens and Quercus oblongifolia did not occur on limestone.

The remaining fifteen species appear to be favored by neither alluvial nor non-alluvial parent materials. Some of those species appear to show no preference to any parent material while others are either favored by one or two parent materials or are restricted by one.

Bouteloua curtipendula, Calliandra eriophylla, Condalia lycioides, Juniperus deppeana, Mimosa dysocarpa, Opuntia spinosior, Parthenium incana, and Prosopis juliflora appear to show no preference for any parent material.

Six species which show no preference for either alluvial or non-alluvial parent materials were greatly limited by one. Acacia constricta, Zinnia pumila, and Ferocactus wislizenii were restricted by volcanic parent materials. Mimosa biuncifera, Quercus arizonica, and Q. emoryi are apparently restricted from limestone.

Juniperus monosperma occurs primarily on alluvium and sandstone.

Two sets of stepwise discriminant analysis were performed at this point: species and parent materials, and species and

elevation-parent material units. Elevation-parent material units were chosen for two reasons. First, because of the difficulty of ordinating parent materials on a continuum or by a meaningful numeric gradient together with the subsequent problem of not being able to average values for parent materials. Second, because of the importance of elevation to plant growth as a surrogate for moisture and temperature and because of the distribution of parent materials with elevation.

To explain the function of the analyses, species and parent materials will be considered. In this analysis, the stepwise discriminant analysis program considers species as "variables" and parent materials as "groups". The species were considered together to discriminate the "groups" (analogous to classes) of parent materials. An identification of species observations (an observation that a particular species occurred on a parent material at a given field sample site) with those parent material groups (= classes) that the set of species is most closely aligned with is the result of the stepwise discriminant analysis. Stepwise discriminant analysis identifies with each group of parent materials an array of species that best correlates as a set with the particular class of parent materials. The program analyzes the species of an observation (species in a field sample site) and then classifies that observation into the parent material group with which it best correlates. If the observation is placed into the parent material group which was

identified as such in the field, then a correct match was made. An overall evaluation can be made of the ability of the parent material classes to be discriminated by the plant species. The uniqueness of each parent material can be judged in this manner. Stepwise discriminant analysis also groups the variables, in this case the species, into the order in which they aid in the discriminating process; that is, the best discriminants of the parent materials.

Results of the two sets of stepwise discriminant analysis were similar. *Cercocarpus breviflorus*, *Rhus choriophylla*, *Agave* spp., *Acacia constricta*, *Opuntia phaeacantha*, *Agave schottii*, *Aloysia wrightii*, and *Mortonia scabrella* were among the best discriminants of groups of elevation-parent material units. Likewise, *Agave* spp. (not including *A. schottii*), *Cercocarpus breviflorus*, *Aloysia wrightii*, *Mortonia scabrella*, *Agave schottii*, *Bouteloua curtipendula*, *Acacia constricta*, and *Quercus emoryi* were the top discriminants of parent materials. Among the poorest discriminants of elevation-parent material units were *Pinus cembroides*, *Dasylirion wheeleri*, *Bouteloua rothrockii*, and *Acacia vernicosa*. *A. vernicosa* was the only species which was also a poor discriminant of parent material classes as well as of elevation-parent material units. Other species poor for discriminating parent materials were *Prosopis juliflora*, *Quercus arizonica*, *Zinnia pumila*, *Opuntia spinosior*, *Mimosa biuncifera*, *Haplopappus tenuisectus*, and *Flourensia cernua*. Figure

42 bears out these relationships, indicating that those species are, indeed, distributed over a wide range of parent materials. It is to be remembered that the stepwise discriminant analysis programs take into account not only the presence of the species, but also the cover values as well.

An interesting observation drawn from these results indicates that grass species were either very good discriminants of parent material classes and elevation-parent material units, or else they were very poor discriminants. Few were intermediate.

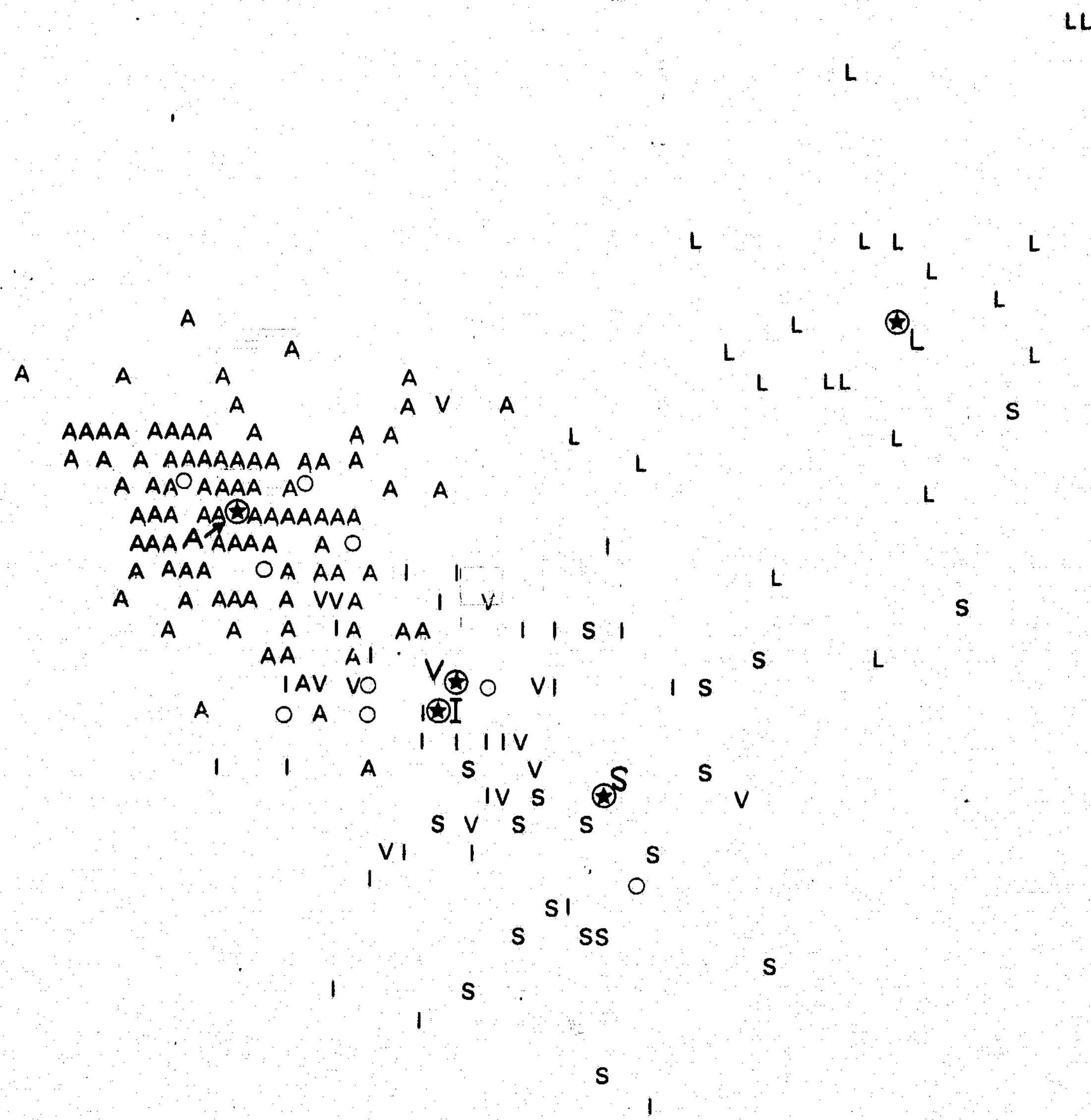
Species appeared to separate parent material classes more effectively than classes of elevation-parent material units. However, on further examination and consideration this is probably because there were five classes of parent materials as opposed to twelve classes of elevation-parent material units. In parent material analyses, four runs were performed. The final run included those species which were the best discriminants among the first three runs. In the final fun (using 41 species), 214 of the 250 observations (field sample sites) were placed in the correct parent material class on the basis of the species information. The alluvial group was especially well identified with 139 of 152 observations (or field sample sites) placed correctly. Among the non-alluvial parent materials, the igneous parent material class was discriminated the poorest with 23 of 32 observations placed correctly.

Figure 42. A scatter diagram of the first two canonical variates[a] where groups are from parent materials and variables are individual plant species.

Symbol	Parent material
A	Alluvium
S	Sedimentary other than limestone
L	Limestone
I	Igneous
V	Volcanics

Ⓐ Group mean values (e. g. A)
O Overlap of values

[a]A linear transformation of the original variate which maximizes the discrimination among the groups.



The twelve classes chosen for the classes of elevation-parent material units included four elevation classes of alluvial parent materials and two elevation classes for each of the non-alluvial parent materials. Results of the two stepwise discriminant analysis funs (41 species in each run) indicated a correct placement of 165 and 175, respectively, of the 250 observations (field sample sites) for each run. The four alluvial groups did not appear to be well classified; 65% of the observations were accurately placed, in comparison to better classification of the other parent materials (73% for limestone, 72% for sandstone, 67% for igneous, and 80% for volcanics). However, the figure is 90% when results of all alluvial classes are combined.

The above discussion duggests the relative indicator value of species with respect to parent materials as well as for the classes of elevation parent material units. Figures 42 and 43 represent a graphic portrayal by the stepwise discriminant analysis of the separation of classes of parent materials and of elevation-parent material units by species. They summarize what was discussed above.

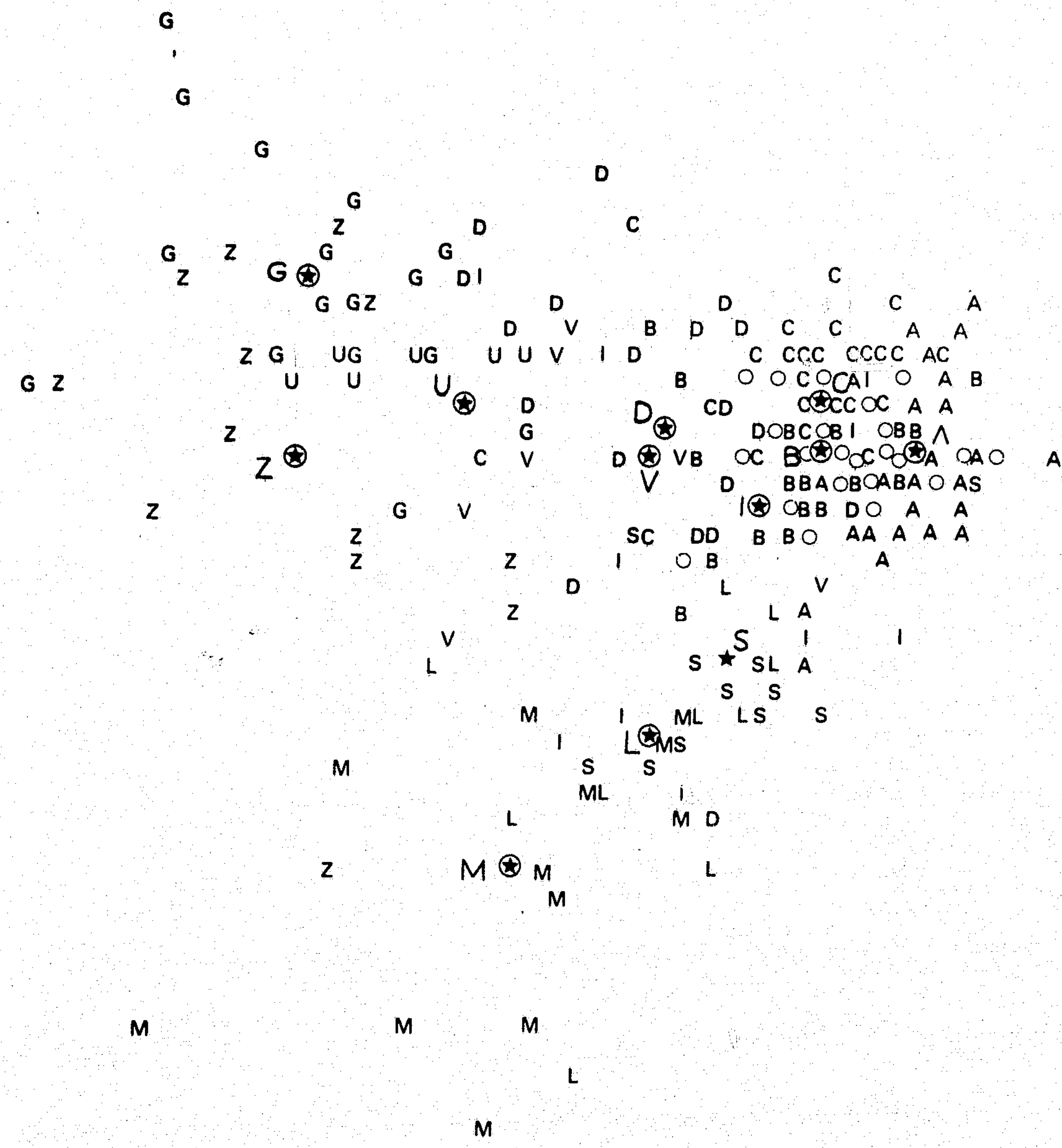
Macrorelief

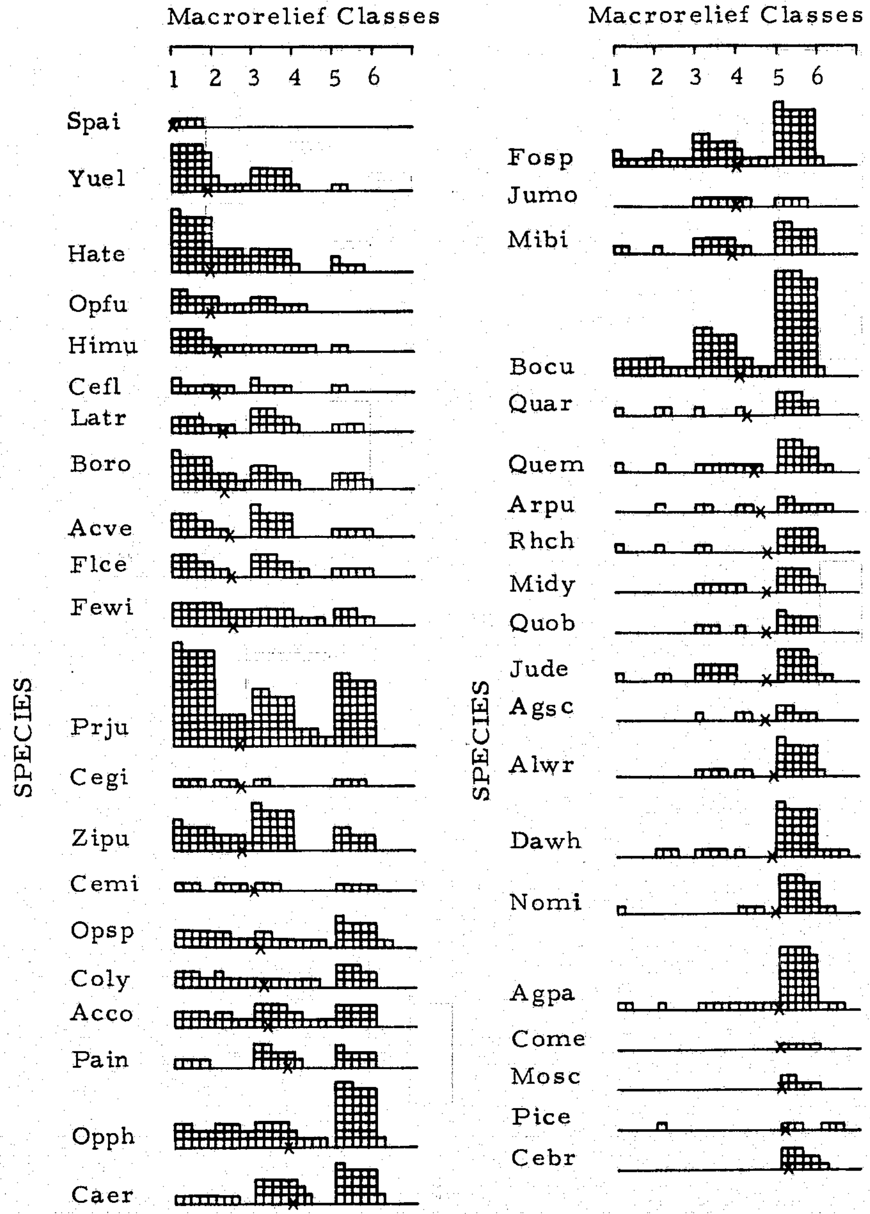
Plant species had a fairly widespread distribution on different types of macrorelief. Figure 44 illustrates this distribution. Some species appeared to occur only on specific macrorelief types while

Figure 43. A scatter diagram of the first two canonical variates where groups are from twelve elevation-parent material units and variables are individual plant species.

Symbol	Elevation-Parent Material Unit
A	Low elevation alluvium
B	Lower middle elevation alluvium
C	Upper middle elevation alluvium
D	Upper elevation alluvium
S	Lower elevation sedimentary other than limestone
Z	Upper elevation sedimentary other than limestone
L	Lower elevation limestone
M	Upper elevation limestone
I	Lower elevation igneous
G	Upper elevation igneous
V	Lower elevation volcanics
U	Upper elevation volcanics

⊛ Group mean values (e. g. A)
O Overlap of values





LEGEND

Flat lands (regional slope < 10%)
- 1 - nondissected
- 2 - dissected (local relief < 10%)

Rolling slopes (10-25%) and moderately dissected lands
- 3 - dissected (local relief 10' to 100', regional slope apparent)
- 4 - rolling (regional slope not apparent)

Hilly and mountainous lands
- 5 - hilly lands (local relief > 100', slopes > 25%)
- 6 - mountainous lands (local relief > 1000', slopes > 25%)

x = mean value
□ = one observation

Figure 44. Distribution of species by macrorelief classes.

others appeared to be uncontrolled or unaffected by it. Upon examination of Figure 44, categories of relationships become apparent. Table 4 illustrates the distribution tendencies of species among macrorelief classes. In it, five categories of distribution tendencies are given.

Two species, Sporobolus aerioides and Hilaria mutica, both grasses, were associated primarily with flat topography (macrorelief class 1).

Nine species were associated primarily with flat and dissected topography (macrorelief classes 1, 2, and 3). They included Yucca elata, Haplopappus tenuisectus, Opuntia fulgida, Cercidium floridum, Larrea tridentata, Bouteloua rothrockii, Acacia vernicosa, Flourensia cernua, and Ferocactus wislizenii.

Eleven species were associated primarily with dissected and hilly topography (macrorelief classes 3, 4, 5, and 6). They included Cercidium microphyllum, Calliandra eriophylla, Parthenium incanum, Fouquieria splendens, Mimosa biuncifera, Quercus arizonica, Q. emoryi, Q. oblongifolia, Juniperus deppeana, J. monosperma, and Mimosa dysocarpa.

Eleven species were associated primarily with hilly and mountainous topography (macrorelief classes 4, 5, and 6). They included Arctostaphylos pungens, Rhus choriophylla, Agave schottii, Agave spp. other than A. schottii, Aloysia wrightii, Dasylirion wheeleri,

Table 4. Distribution tendencies of species among macrorelief classes.

Macrorelief Class 1 (primarily flat)

Species: Himu, Spai

Macrorelief Classes 1, 2, & 3 (flat and dissected)

Species: Yuel, Hate, Opfu, Cefl, Latr, Boro, Acve, Flce, Fewi

Macrorelief Classes 3, 4, 5, & 6 (dissected and hilly)

Species: Cemi, Caer, Pain, Fosp, Mibi, Quar, Quem, Quob, Jude, Jumo, Midy

Macrorelief Classes 4, 5, & 6 (hilly and mountainous)

Species: Arpu, Rhch, Agsc, Agpa, Alwr, Dawh, Nomi, Come, Cebr, Mosc, Pice

Wide range of Macrorelief Classes

Species: Prju, Cegi, Zipu, Opsp, Coly, Acco, Opph, Bocu

Nolina microcarpa, Cowania mexicana, Cercocarpus breviflorus, Mortonia scabrella, and Pinus cembroides.

The remaining eight species did not appear to be associated with any macrorelief class or group of classes. They included Prosopis juliflora, Cereus giganteus, Zinnia pumila, Opuntia spinosior, Condalia lycioides, Acacia constricta, Opuntia phaeacantha, and Bouteloua curtipendula.

Drainage density

The distribution of plant species according to drainage density is graphed in Figure 45. While at first glance results appear to be vague, when groups of values are considered, results are more apparent. Table 5 illustrates the distribution tendencies of species among drainage densities.

Drainage density values ranged from zero to 14.3 mi./mi.^{2} with most values occurring between 4.0 and 8.0 mi./mi.^{2} Three classes of drainage density were developed. Those observations which were considered to have low drainage densities had values ranging from zero to 4.9 mi./mi.^{2} Medium drainage densities ranged from 5.0 to 7.2 mi./mi.^{2} The high drainage density category consisted of those values over 7.2 mi./mi.^{2} Drainage density tended to vary directly with elevation. Low elevation observations had low drainage densities on both alluvial and

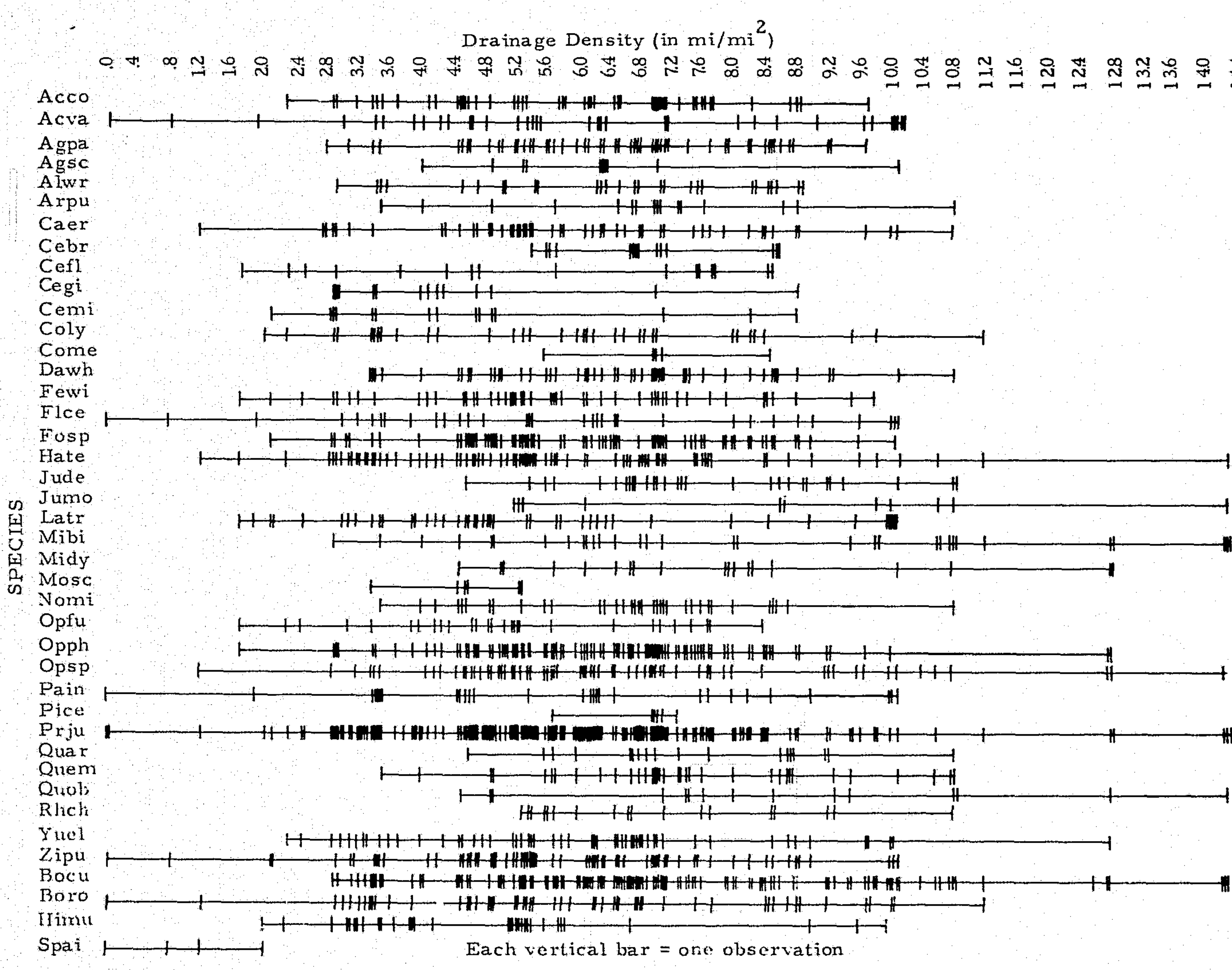


Figure 45. Distribution of species by drainage density.

Table 5. Distribution tendencies of species among drainage densities.

Low Drainage Density (Dd generally < 6.0 mi./mi.^{2})

Species: Flce, Latr, Opfu, Hate, Spai, Cegi, Cemi, Himu, Mosc

Wide range of Drainage Density but with concentration on low values (Dd generally < 7.0 mi./mi.^{2})

Species: Acco, Prju, Yuel

Wide range of Drainage Density but with concentration on middle values (Dd generally 4.5 to 8.0 mi./mi.^{2})

Species: Agpa, Agsc, Caer, Dawh, Fewi, Fosp, Opsp, Opph, Zipu

Wide range of Drainage Density

Species: Acve, Cefl, Coly, Pain, Boro

Wide range of Drainage Density but with concentration on high values (Dd generally > 5.0 mi./mi.^{2})

Species: Alwr, Arpu, Bocu

High Drainage Density (Dd generally > 6.0 mi./mi.^{2})

Species: Jude, Cebr, Come, Rhch, Pice, Quob, Quem, Quar, Jumo, Midy, Mibi, Nomi

non-alluvial parent materials. High elevation observations had relatively high drainage densities. Of the non-alluvial parent materials, limestone had the lowest values. The highest drainage densities occurred on alluvial parent materials in high elevations.

Six categories of observations were drawn from Figure 45 and listed in Table 5. Those species which tended to occur in low drainage densities included Flourensia cernua, Larrea tridentata, Opuntia fulgida, Haplopappus tenuisectus, Sporobolus aerioides, Cereus giganteus, Cercidium microphyllum, Hilaria mutica, and Mortonia scabrella.

Those species which occurred over a wide range of drainage densities but with a concentration on lower values included Acacia constricta, Prosopis juliflora, and Yucca elata.

Those species which occurred over a wide range of drainage densities but with a concentration on middle values (drainage density generally between 4.5 and 8.0 mi./mi.^{2}) included Agave spp. other than A. schottii, A. schottii, Calliandra eriophylla, Dasylirion wheeleri, Ferocactus wislizenii, Fouquieria splendens, Opuntia spinosior, O. phaeacantha, and Zinnia pumila.

Those species which occurred over a wide range of drainage densities without apparent concentration on any set of values included Acacia vernicosa, Cercidium floridum, Condalia lycioides, Parthenium incanum, and Bouteloua rothrockii.

Those species which occurred over a wide range of drainage densities but with a concentration on high values (drainage density generally over 5.0 mi./mi.^{2}) included Aloysia wrightii, Arctostaphylos pungens, and Bouteloua curtipendula.

Those species which tended to occur only in areas of high drainage density (drainage density generally over 6.0 mi./mi.^{2}) included Juniperus deppeana, Cercocarpus breviflorus, Cowania mexicana, Rhus choriophylla, Pinus cembroides, Quercus oblongifolia, Q. emoryi, Q. arizonica, Juniperus monosperma, Mimosa dysocarpa, M. biuncifera, and Nolina microcarpa.

Drainage densities might be used as indicators of vegetation as they seem to correlate well with elevation which, through its effect on soil moisture and temperature, bears a strong relationship to vegetation. Drainage density is a fairly accurately interpreted terrain variable on aerial photography and can therefore serve as a useful tool in the interpretation of vegetation.

Drainage density when combined with macrorelief can be useful as an aid in the interpretation of internal and external drainage. For this reason, groups of drainage density and macrorelief classes were established and computer runs using stepwise discriminant analysis were performed. The following categories, or groups were developed:

1) low drainage density on flat topography (macrorelief class 1)
2) medium drainage density on flat topography (macrorelief class 1)

3) high drainage density on flat topography (macrorelief class 1)

4) low drainage density on dissected topography (macrorelief classes 2 and 3)

5) medium drainage density on dissected topography (macrorelief classes 2 and 3)

6) high drainage density on dissected topography (macrorelief classes 2 and 3)

7) low drainage density on hilly and mountainous topography (macrorelief classes 4, 5, and 6)

8) medium drainage density on hilly and mountainous topography (macrorelief classes 4, 5, and 6)

9) high drainage density on hilly and mountainous topography (macrorelief classes 4, 5, and 6)

Agave spp. not including A. schottii and Bouteloua curtipendula were the best discriminants of the above drainage density and macrorelief groups. Parthenium incanum, Yucca elata, Zinnia pumila, Agave schottii, Cercocarpus breviflorus, Cereus giganteus, Opuntia phaeacantha, and Juniperus deppeana were also good discriminants of the drainage density and macrorelief groups. The poorest discriminants were Juniperus monosperma, Dasylirion wheeleri, Opuntia fulgida, Ferocactus wislizenii, Acacia constricta, and Flourensia cernua. The stepwise discriminant analysis resulted in 60% of the observations of the drainage density-macrorelief classes

(the observation that a certain drainage density-macrorelief type occurred at a given field sample site) being identified correctly on the basis of the association between the species included in the analysis and the classes of drainage density-macrorelief types. The groups classified or identified most accurately, were the low, medium, and high drainage densities associated with hilly and mountainous topography. That is, those groups were best separated or discriminated by the species. The groups discriminated least accurately were the low, medium, and high drainage densities associated with dissected topography (macrorelief classes 2 and 3).

Landform

The associations of landforms and species indicates a range from species occurring on one specific landform type to species occurring on a wide variety of landform types. In the preliminary data analysis, landform types occurring with each species (according to species) were noted. As the list of landform types associated with each species was quite long and certainly tedious to examine, the list was reduced to include only the principal landform types associated with each species. That list has been transformed into Table 6 which shows the distribution tendencies of species among landform types. Only those species which would most likely be associated with the landform types have been listed.

Table 6. Distribution tendencies of species amon g landform types.

Alluvial Landforms	Species
Floodplains & terraces	Acco, Cefl, Coly, Hate, Himu, Opfu
Smooth alluvial surfaces (other than floodplains & terraces)	Acco, Acve, Cegi, Fewi, Flce, Hate, Himu, Latr, Nomi, Opfu, Opph, Spai, Yuel
Alluvial interfluves	Acco, Acve, Bocu, Cemi, Fewi, Flce, Fosp, Hate, Himu, Jumo, Latr, Opfu, Opph, Pain
Side slopes of dissected bajadas	Acve, Bocu, Cemi, Jumo, Latr, Pain, Zipu
Alluvial in general	Boro, Cefl, Fosp, Mibi, Opsp, Prju
Non-Alluvial Landforms	
Upper convex slopes	Agsc, Come, Dawh, Opph
Middle or undifferentiated slopes	Acco, Acve, Agpa, Agsc, Alwr, Arpu, Bocu, Boro, Caer, Cebr, Cemi, Coly, Come, Dawh, Fosp, Jude, Mibi, Midy, Mosc, Nomi, Opph, Opsp, Pain, Prju, Quar, Quem, Quob, Zipu
Lower concave slopes	Fewi, Flce, Pice
Pediments	Cegi, Opfu

Slope angle

It would be expected that relationships between slope angles and plant species would be somewhat similar to the relationships between macrorelief and plant species. Species that occur predominantly on flat topography would also tend to occur on slopes of low angle, while species occurring on hilly and mountainous topography would also tend to occur on slopes of high angle. Figure 46 illustrates the distribution of species according to slope angle class. The array of species according to slope angle class was grouped into five classes or categories of relationships of species among slope angle classes. Table 7 represents the distribution tendencies of the species among slope angles.

Those species which occur on the lowest slope angles are predominantly the same species which occurred primarily on alluvial parent materials and on low macrorelief classes. They include *Sporobolus aerioides*, *Haplopappus tenuisectus*, *Opuntia fulgida*, *Hilaria mutica*, *Yucca elata*, and *Cercidium floridum*. Those species occur primarily on slopes under 10% (slope angle classes 1, 2, and 3) with *Sporobolus aerioides* and *Haplopappus tenuisectus* occurring on very gentle slopes (under 3%).

Ten species occurred on a wide range of slope angles although they occurred primarily on lower slope angles (averaging 8% to 25%).

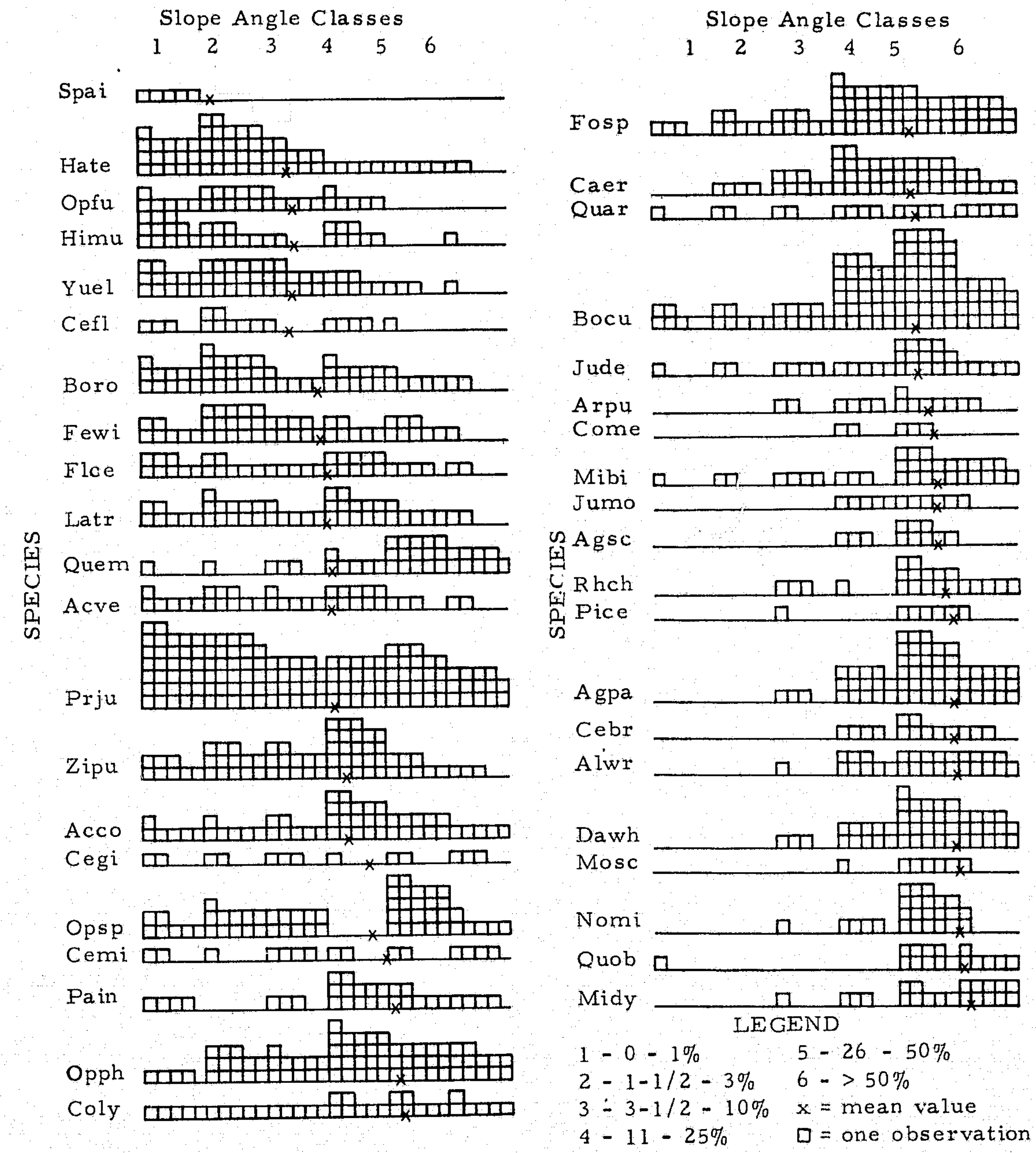


Figure 46. Distribution of species by slope angle classes.

Table 7. Distribution tendencies of species among slope angles.

Low Slope Angles (averaging < 5%)

Species: Cefl, Hate, Himu, Opfu, Spai, Yuel

Wide range of Slope Angles (primarily lower slope angles averaging 8-25%)

Species: Acco, Acve, Boro, Cegi, Cemi, Fewi, Flce, Latr, Prju, Zipu

Wide range of Slope Angles (primarily higher slope angles averaging 20-40%)

Species: Arpu, Bocu, Caer, Coly, Fosp, Jude, Mibi, Opph, Opsp, Pain, Quar

Moderately High Slope Angles (averaging 37-50%)

Species: Agsc, Come, Jumo, Pice, Rhch

High Slope Angles (averaging > 45%)

Species: Agpa, Alwr, Cebr, Dawh, Midy, Mosc, Nomi, Quob

They included Bouteloua rothrockii, Ferocactus wislizenii, Flourensia cernua, Larrea tridentata, Acacia vernicosa, Prosopis juliflora, Zinnia pumila, Acacia constricta, Cereus giganteus, and Cercidium microphyllum.

Twelve species occurred over a wide range of slope angles although they occurred primarily on the higher slope angles (averaging 20% to 40%). They included Opuntia spinosior, Parthenium incanum, Opuntia phaeacantha, Condalia lycioides, Fouquieria splendens, Calliandra eriophylla, Quercus arizonica, Q. emoryi, Bouteloua curtipendula, Juniperus deppeana, Arctostaphylos pungens, and Mimosa biuncifera.

Five species occurred primarily on moderately high slope angles (averaging 37% to 50%). They included Cowania mexicana, Agave schottii, Rhus choriophylla, Pinus cembroides, and Juniperus monosperma.

The remaining eight species occurred primarily on the higher slope angles (averaging slope angles of over 45%). They included Agave spp. not including A. schottii, Cercocarpus breviflorus, Aloysia wrightii, Dasylirion wheeleri, Mortonia scabrella, Nolina microcarpa, Quercus oblongifolia, and Mimosa dysocarpa.

A relatively close relationship exists between slope angle and species distribution. The relationship appears to be especially positive for those species which occur on gentle slopes and for those

species which occur on the steeper slopes. That is, ,species occurring on the lowest and highest slopes do not tend to occur elsewhere.

Slope aspect

The association of slope aspect with species proved to be rather disappointing (see Figure 47). Although only higher slope angle observations were placed in an aspect class other than level, species still tended to occur over a wide range of slope aspects. Most species which occurred most often on high average aspect values (indicating a tendency toward northeasterly aspects) or low average aspect values (indicating a tendency toward southwesterly aspects) had a number of observations on the opposite aspect classes. In considering the distribution tendencies of species among the aspect classes, the species were grouped into only three categories of slope aspect: southerly aspects, northerly aspects, and little aspect preference or primarily level, see Table 8.

Eight species occurred primarily on the southerly aspects. They included Cercidium microphyllum, Calliandra eriophylla, Cereus giganteus, Ferocactus wislizenii, Parthenium incanum, Mimosa dysocarpa, Agave schottii, and Cowania mexicana.

Ten species occurred primarily on the northerly aspects. They included, from the most northerly, Pinus cembroides, Quercus oblongifolia, Juniperus monosperma, Rhus choriophylla,

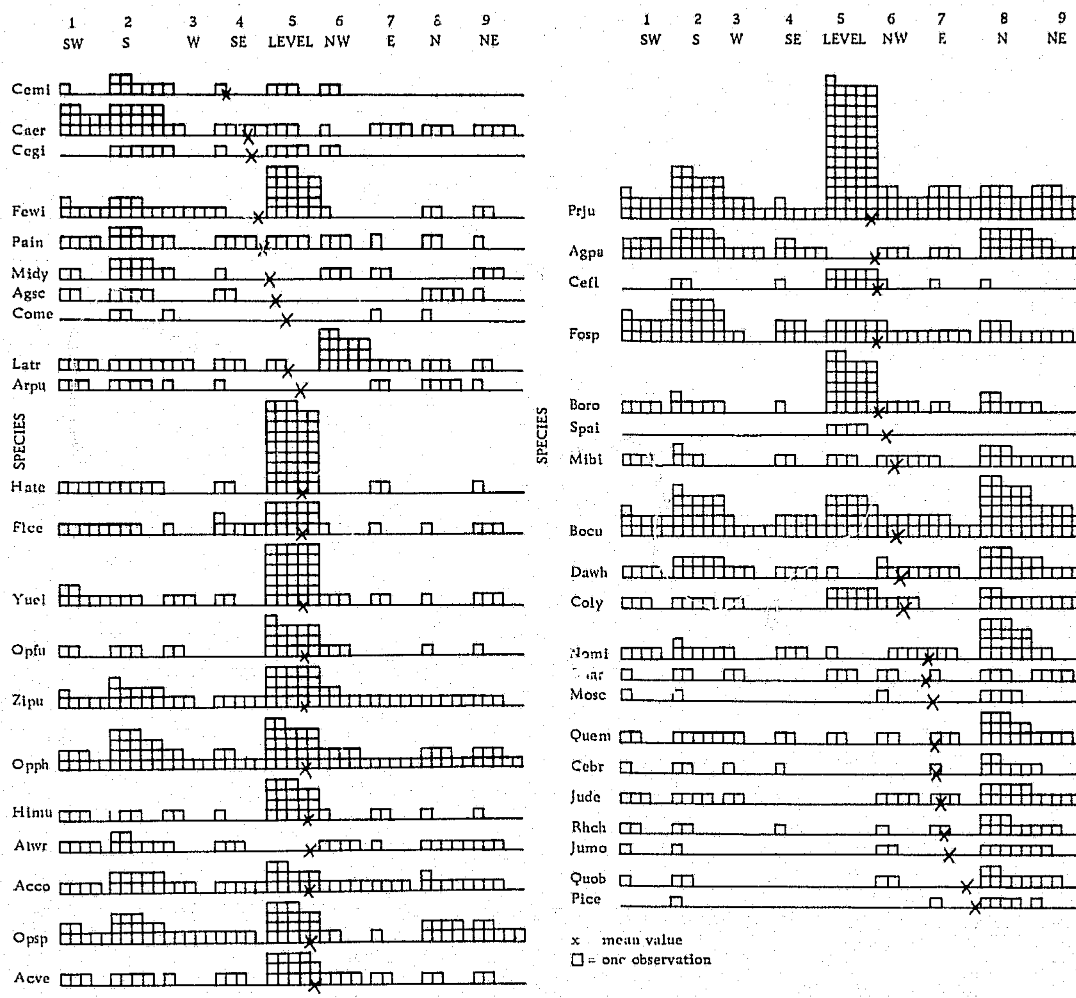


Figure 47. Distribution of species by aspect.

ORIGINAL PAGE IS OF POOR QUALITY

Juniperus deppeana, Cercocarpus breviflorus, Quercus emoryi, Mortonia scabrella, Quercus arizonica, and Nolina microcarpa.

The remaining twenty-three species have an indefinite relationship to slope aspect, occurring on both northerly and southerly aspects with more or less the same frequency.

Table 8. Distribution tendencies of species among aspect classes.

Southerly Aspects

Species: Agsc, Caer, Cegi, Cemi, Come, Fewi, Midy, Pain

Little aspect preference or primarily level

Species: Acco, Acve, Agpa, Alwr, Arpu, Bocu, Boro, Cefl, Coly, Dawh, Flce, Fosp, Hate, Himu, Jumo, Latr, Mibi, Opfu, Opph, Opsp, Prju, Spai, Yuel, Zipu

Northerly Aspect

Species: Cebr, Jude, Jumo, Mosc, Nomi, Pice, Quar, Quem, Quob, Rhch

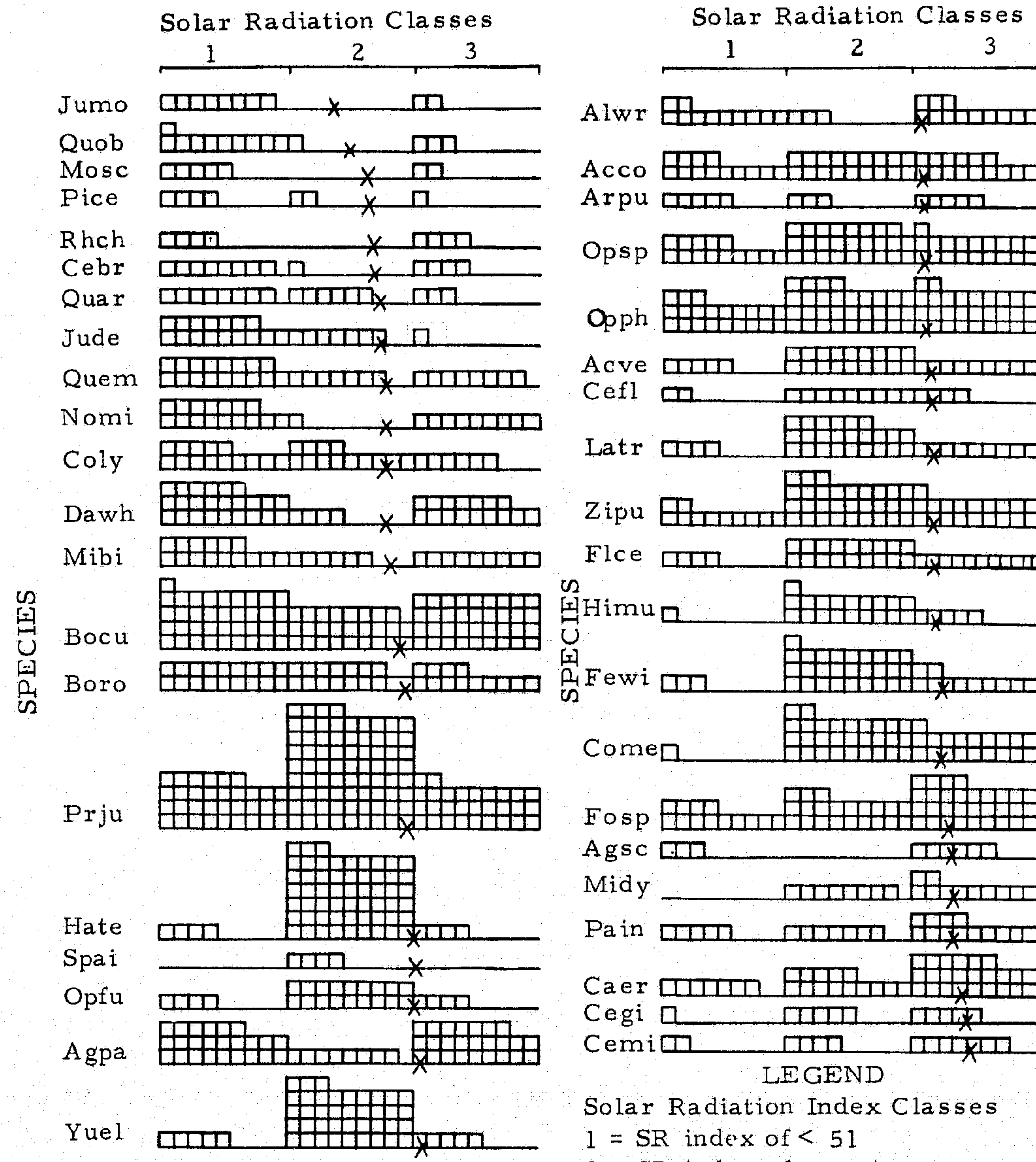
Solar radiation index

Since the solar radiation index (described at greater length in "Methods") is a function of slope aspect and slope angle, one would expect low values of solar radiation index for observations occurring on steep northerly slopes and high values for observations (field sample sites) occurring on steep southerly slopes. The species occurring at each field sample site are attributed the value of the solar radiation index for that site. Relative indices of solar radiation

were grouped into three categories: low, average, and high. The distribution of the species according to those classes is illustrated in Figure 48. The distribution tendencies of the species among the solar radiation classes is given in Table 9. The bi-modality in distribution of species at low values of solar radiation index is due to those species occurring primarily on north and south slope aspects of at least moderate declivity.

The same ten species, although not in the same order, which had the most northerly slope aspects also had the lowest solar radiation values. They included (from the lowest value) Juniperus monosperma, Quercus oblongifolia, Mortonia scabrella, Pinus cembroides, Rhus choriophylla, Cercocarpus breviflorus, Quercus arizonica, Juniperus deppeana, Quercus emoryi, Nolina microcarpa; in addition, Condalia lycioides was considered to have a fairly positive relationship with low solar radiation index values.

Concomitantly, the same eight species which exhibited positive relationships to southerly aspects occurred on sites having relatively high solar radiation index values. They included (in order from the highest value) Cercidium microphyllum, Cereus giganteus, Calliandra eriophylla, Parthenium incanum, Mimosa dysocarpa, Agave schottii, Cowania mexicana, and Ferocactus wislizenii. In addition, Fouquieria splendens was observed to occur primarily on sites having higher solar radiation index values.



LEGEND

Solar Radiation Index Classes

1 = SR index of < 51

2 = SR index of 51-54

3 = SR index of > 54

x = mean value

□ = one observation

Figure 48. Distribution of species by solar radiation index classes.

Table 9. Distribution tendencies of species among solar radiation index values.

Low Solar Radiation index

Species: Cebr, Jude, Jumo, Mosc, Nomi, Pice, Quar, Quem, Quob, Rhch

Average Solar Radiation index

Species: Acco, Acve, Agpa, Alwr, Arpu, Bocu, Boro, Cefl, Coly, Dawh, Flce, Hate, Himu, Latr, Mibi, Opfu, Opph, Opsp, Prju, Spai, Yuel, Zipu

High Solar Radiation index

Species: Agsc, Caer, Cegi, Cemi, Come, Fewi, Fosp, Midy, Pain

The final stepwise discriminant analysis involving plant species was an analysis which included slope angle and slope aspect classes. Observations were separated as to parent material: alluvial versus non-alluvial parent materials. The categories were as follows:

Alluvial parent materials

Low slope angle (classes 1 and 2)

High slope angles (classes 3, 4, 5, and 6) and on northerly aspects

High slope angles (classes 3, 4, 5, and 6) and on southerly aspects

Non-alluvial parent materials

High slope angles (classes 3, 4, 5, and 6) and on northerly aspects

High slope angles (classes 3, 4, 5, and 6) and on southerly aspects

A low angle, non-alluvial class was not included because of the limited observations in this class.

Stepwise discriminant analysis resulted in an excellent separation of alluvial and non-alluvial parent materials, as Figure 49 illustrates (observations classed into groups L, S, and N from X and M). It also produced a good separation of the three categories of alluvial parent material observations (that is, groups L, S, and N). Considerable mixing of observations within the two classes of non-alluvial parent materials is illustrated in the scatter diagram.

The species which were determined to be the best discriminants of the categories of parent material, slope aspect, and slope angle included _Agave_ spp. not including _A. schottii_, _Bouteloua curtipendula_, _Fouquieria splendens_, _Prosopis juliflora_, _Nolina microcarpa_, _Opuntia phaeacantha_, and _Juniperus monosperma_. The poorest discriminants included _Opuntia fulgida_, _Juniperus deppeana_, _Ferocactus wislizenii_, _Dasylirion wheeleri_, _Hilaria mutica_, and _Yucca elata_.

Relationships Between Vegetation Types and Terrain Variables

The relationships of vegetation types with terrain variables will be considered in a similar fashion to the relationships of the

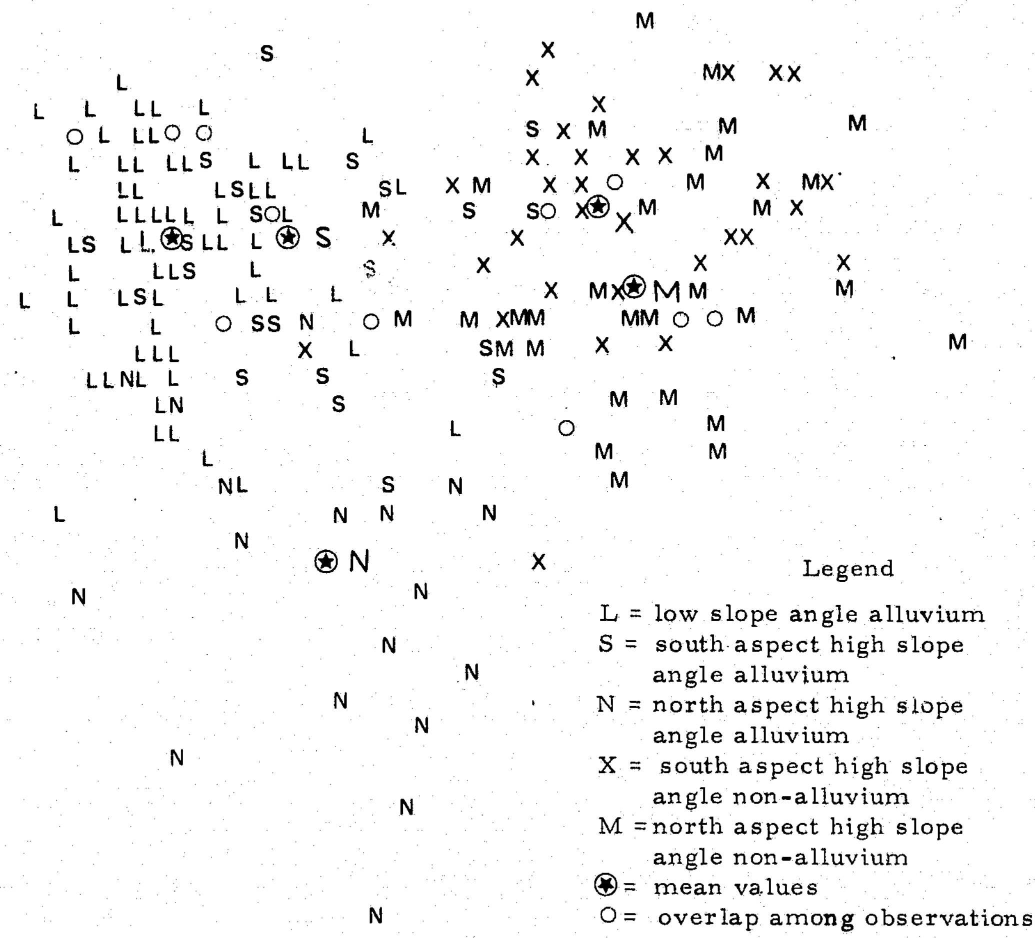


Figure 49. A scatter diagram of the first two canonical variates where groups are from parent materials, aspect, and slope angle, and variables are individual plant species.

individual plant species with the terrain variables. The ecological amplitudes of the vegetation types for the terrain variables are included in this section. In addition, the ability of terrain variables to discriminate vegetation types will also be discussed.

The range of vegetation types across the individual terrain variables is narrower in most instances than are the ranges of individual plant species. A probable explanation for this observation is that the community or vegetation type, being a socially compatible group of species presents an integration of the ecological amplitudes of all its component species. Many of those species are members of other vegetation types. Thus, each vegetation type reflects a narrower ecological amplitude by truncating that part of the species amplitude that represents its occurrence in other vegetation types.

In the following discussion each vegetation type is identified by a number, a description, and an abbreviated name (see Table 10). The numbers are used in tables and figures and the abbreviated names in the text.

Elevation

The distribution of vegetation types on an elevational gradient is shown in Figure 50. Mean elevational figures in addition to the elevational location of individual sites are included in the figure and show that some vegetation types have broad ranges while others

Table 10. Vegetation types used in the analysis of relationships between vegetation types and terrain variables.

Identifier number	Descriptive name and short title	Abbreviated Alpha title
2	Larrea tridentata with Prosopis juliflora and/or Opuntia (cholla). = Larrea tridentata with Prosopis juliflora	Latr
3	Cercidium microphyllum and Cereus giganteus often with Encelia farinosa and Opuntia, (without Franseria deltoidea). = Cercidium microphyllum	Cemi
6	Prosopis juliflora and Haplopappus tenuisectus with Opuntia (cholla), (without Acacia constricta and Calliandra eriophylla). = Prosopis juliflora with Opuntia spp. (cholla)	Opun
7	Prosopis juliflora and Haplopappus tenuisectus, (without Acacia constricta, Opuntia (cholla), and Calliandra eriophylla). = Prosopis juliflora (without Opuntia spp. - cholla)	Prju
8	Calliandra eriophylla usually with Acacia constricta, Fouquieria splendens, and Prosopis juliflora, (without Coldenia canescens). = Acacia constricta with Calliandra eriophylla	Caer
9	Acacia constricta and Prosopis juliflora usually with Opuntia, (without Calliandra eriophylla). = Acacia constricta (without Calliandra eriophylla	Acco
10	Acacia vernicosa, Flourensia cernua, and Larrea tridentata, (without Rhus microphylla and Dalea formosa). = Acacia vernicosa (without Rhus microphylla	Acve
11	Acacia vernicosa, Flourensia cernua, Larrea tridentata, and Rhus microphylla. = Acacia vernicosa with Rhus microphylla	Rhus
12	Aloysia wrightii usually with Fouquieria splendens, Acacia constricta, and Opuntia (prickly pear). = Aloysia wrightii	Alwr
14	Mortonia scabrella (without Rhus choriophylla). = Mortonia scabrella	Mosc
15	Prosopis juliflora and Bouteloua, (without Nolina microcarpa, Quercus, and Juniperus). = Prosopis juliflora/Bouteloua spp.	PrBo
16	Prosopis juliflora and Bouteloua with Quercus (usually Q. oblongifolia and/or Juniperus deppeana. = Prosopis juliflora/Bouteloua spp. with Quercus spp.	PrBQ
17	Bouteloua, Aristida, and Nolina microcarpa, (without Calliandra eriophylla. = Bouteloua spp./Nolina microcarpa	BoNo

Table 10. Continued

Identifier number	Descriptive name and short title	Abbreviated Alpha title
18	Bouteloua and Aristida (without large shrubs, Nolina microcarpa, Yucca, and Calliandra eriophylla). = Bouteloua spp. (without Nolina microcarpa)	Bout
19	Calliandra eriophylla and Bouteloua with any or all of Ephedra trifurca, Yucca baccata, Y. elata, and Prosopis juliflora, (without Acacia constricta). = Bouteloua spp./Yucca elata	BoYu
21	Sporobolus wrightii often with Prosopis juliflora. = Sporobulus wrightii	Spwr
22	Hilaria mutica and Prosopis juliflora. = Hilaria mutica	Himu
23	Cercocarpus breviflorus with Juniperus deppeana and/or Pinus cembroides and usually with Quercus. Cercocarpus breviflorus	Cebr
24	Quercus, Arctostaphylos pungens, Pinus cembroides, and Juniperus deppeana, (without Mimosa biuncifera). = Quercus spp./Arctostaphylos pungens (without Mimosa biuncifera)	QuAr
25	Quercus and Arctostaphylos pungens usually with Mimosa biuncifera, (without Pinus cembroides). = Quercus spp./Arctostaphylos pungens with Mimosa biuncifera	QAMi
26	Cowania mexicana usually with Juniperus. = Cowania mexicana	Come
27	Quercus and Mimosa (without Arctostaphylos pungens and Cercocarpus breviflorus). = Quercus spp./Mimosa biuncifera	QuMi
29	Populus fremontii, Fraxinus velutina, Platanus wrightii, and/or Chilopsis linearis. = riparian	Ripa
30	Quercus and Nolina microcarpa (without Cercocarpus breviflorus, Arctostaphylos pungens, and Mimosa biuncifera). = Quercus spp./ Nolina microcarpa	QuNo
31	Calliandra eriophylla and Bouteloua usually with any or all of Fouquieria splendens, Acacia greggii, Mimosa biuncifera, M. dysocarpa, and Ferocactus wislizenii, (without Acacia constricta). = Bouteloua spp./Fouquieria splendens	BoFo

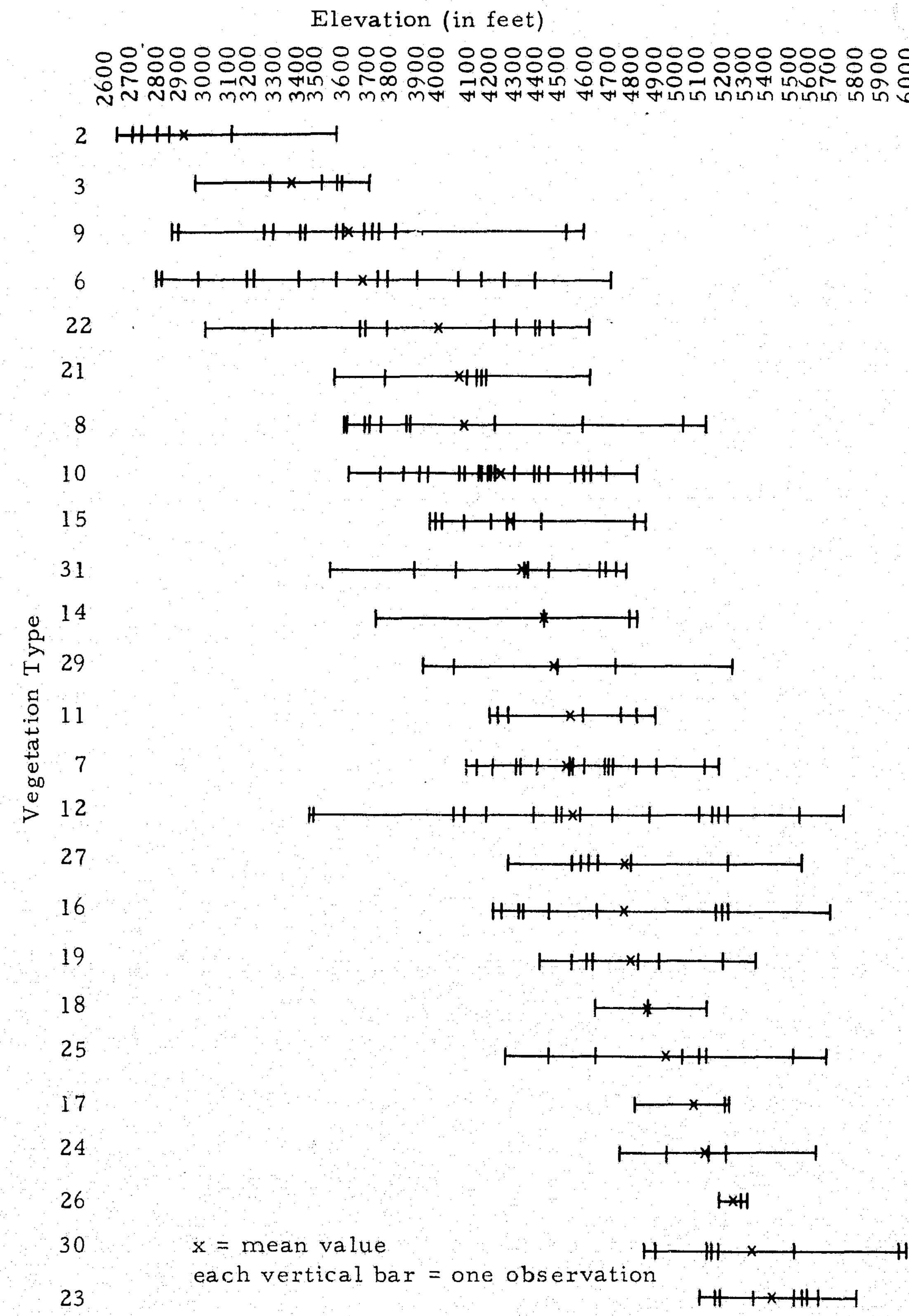


Figure 50. Distribution of vegetation types by elevation.

are narrowly defined. In Table 11, the elevational distribution of the vegetation types have been grouped into four elevation classes.

The Larrea tridentata with Prosopis juliflora type (2) and the Cercidium microphyllum type (3) are restricted to the lowest elevations within the study area, occurring primarily below 3, 600 feet. The other vegetation types that are considered to occur at low elevations within the study area include the Acacia constricta (without Calliandra eriophylla) type (9), the Prosopis juliflora with Opuntia spp. (cholla) type (6), and the Hilaria mutica type (22). Those three types are found to occur primarily between 3, 000 feet and 4, 500 feet.

Ten vegetation types are considered to occur in the lower middle elevations of the study area. The Sporobolus wrightii type (21) and the Hilaria mutica type (22), discussed above, are both grassland types occurring in similar types of environments. The Acacia constricta with Calliandra eriophylla type (8) is a type having a fairly wide elevation range although most observations occur in a narrow cluster between 3, 600 feet and 3, 900 feet. The Acacia vernicosa (without Rhus microphylla) type (10), a very widespread vegetation type in the upper San Pedro Valley, has an average elevation of 4, 300 with a total range of about 1, 300 feet. Most of the observations are clustered about the mean, though. A closely related type, Acacia vernicosa with Rhus microphylla (11), occurs at elevations nearly 500 feet higher than the Acacia vernicosa

Table 11. Distribution tendencies of vegetation types among elevation groups.

Low Elevation

mean: 2,900' to 3,400'
range: primarily 2,700' to 3,600'
vegetation types: 2, 3 (very low)

mean: 3,600' to 4,000'
range: primarily 3,000' to 4,500'
vegetation types: 9, 6, 22

Lower Middle Elevation

mean: 4,100' to 4,500'
range: primarily 3,700' to 5,200'
vegetation types: 21, 8, 10, 15, 31, 14, 29, 11, 7, 12

Upper Middle Elevation

mean: 4,750' to 4,900'
range: primarily 4,200' to 5,500'
vegetation types: 27, 16, 19, 18, 25

High Elevation

mean: 5,050' to 5,350'
range: primarily 4,750' to 5,750'
vegetation types: 17, 24, 26, 30, 23

(without Rhus microphylla) type (10). One of the principal grassland types, Prosopis juliflora/Bouteloua spp. (15), is located at approximately the same elevation as the Acacia vernicosa (without Rhus microphylla) type (10). The Bouteloua spp. /Fouquieria splendens type (31) is also located at about the same elevation as the above two types (15 and 10). The Mortonia scabrella type (14), which is an important vegetation type occurring in the limestone hills around Tombstone, has a fairly wide elevation range since it occurs in drainageways. It is distributed between 3,800 feet and 5,300 feet. Limited sampling of the type precluded documentation of occurrences at higher or lower elevations. The Prosopis juliflora (without Opuntia spp. (chollas) type (6). In fact, the elevation ranges for the two vegetation types barely overlap. The vegetation type having the widest observed elevation range is the Aloysia wrightii type (12), see Figure 50.

Five vegetation types are considered to occur in the upper middle elevations of the study area. That elevational group ranges approximately between 4,200 feet to 5,500 feet, with a mean elevation primarily between 4,750 feet and 4,900 feet. Two of the oak types have very similar elevation ranges. They include the Quercus spp. / Mimosa biuncifera type (27) and the Prosopis juliflora/Bouteloua spp. with Quercus spp. type (16). A third oak type, Quercus spp. / Arctostaphylos pungens with Mimosa biuncifera (25) occurs at

slightly higher elevations. The other two vegetation types included in this elevation category have narrow elevation ranges. They include the Bouteloua spp. /Yucca elata type (19) and the Bouteloua spp. (without Nolina microcarpa) type (18).

The remaining five vegetation types are all high-elevation types occurring primarily over 5,000 feet and having fairly limited observed elevation ranges within the study area. The Bouteloua spp. / Nolina microcarpa type (17) is a high elevation grassland. The Quercus spp. /Arctostaphylos pungens (without Mimosa biuncifera) type (24), the Cowania mexicana type (26), the Quercus spp. /Nolina microcarpa type (30), and the Cercocarpus breviflorus type (23) also occur in the highest elevation class within the study area.

Parent materials

Unlike the relationships between the individual species and terrain variables, vegetation types appear to have quite definite associations with parent materials. Most vegetation types have a strong association with just one or two parent materials. Figure 51 illustrates the relation of vegetation types with respect to parent materials. Table 12 illustrates the distribution tendencies of vegetation types among parent materials.

Twelve vegetation types occur primarily on alluvial parent materials. The Larrea tridentata type (2), the Prosopis juliflora

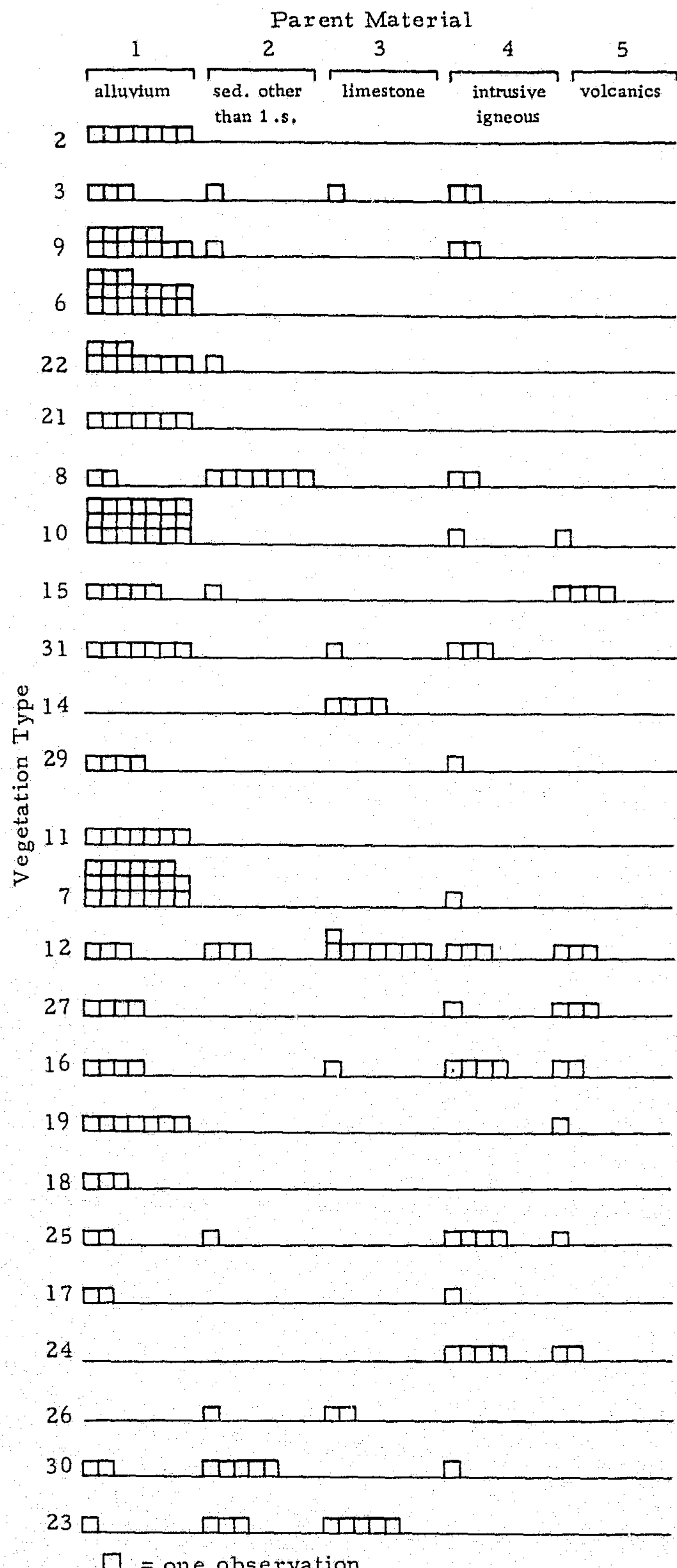


Figure 51. Distribution of vegetation types by parent materials.

Table 12. Distribution tendencies of vegetation types among parent materials.

Vegetation Types	Parent Material: Alluvium	Sandstone	Limestone	Igneous	Volcanics
Occurring two or more times on:	2, 3, 6, 7, 8, 9, 10, 11, 12, 15, 16, 17 18, 19, 21, 22, 25, 27, 29, 30, 31 (21 types)	9, 12, 23, 30 (4 types)	12, 14, 23, 26 (4 types)	3, 8, 9, 12, 16, 24, 25, 31 (8 types)	12, 15, 16, 24, 27 (5 types)
Occurring primarily on:	2, 6, 7, 9, 10, 11, 17, 18, 19, 21, 22, 29 (12 types)	8, 30 (2 types)	14, 23, 26 (3 types)	24, 25 (2 types)	none
Absent or nearly absent on:	8, 12, 14, 23, 24, 26, 30 (7 types)	2, 6, 7, 10, 11, 14, 16, 17, 18, 19, 21, 24, 27, 29, 31 (15 types)	2, 6, 7, 8, 9, 10, 11, 15, 17, 18, 19, 21, 22, 24, 25, 27, 29 30 (18 types)	2, 6, 11, 14, 15, 18, 18, 21, 22, 23, 26 (11 types)	2, 3, 6, 7, 8, 9, 11, 14, 17, 18, 21, 22, 23, 26, 29, 30, 31

with Opuntia spp. (chollas) type (6), the Sporobolus wrightii type (21), the Acacia vernicosa with Rhus microphylla type (11), and the Bouteloua spp. (without Nolina microcarpa) type (18) occur exclusively on alluvial parent materials. The remaining seven vegetation types occur primarily on alluvial parent materials. Those include the Prosopis juliflora (without Opuntia spp. - chollas) type (7), the Acacia vernicosa (without Calliandra eriophylla) type (9), the Acacia vernicosa (without Rhus microphylla) type (10), the Bouteloua spp. /Nolina microcarpa type (17), the Yucca elata/Bouteloua spp. type (19), the Hilaria mutica type (22), and the riparian type (29). More than 80% of the vegetation types occur two or more times on alluvial parent materials, while only seven or 28% of the vegetation types are absent or nearly absent from alluvial parent materials, see Table 12.

Two vegetation types occur primarily on sandstone parent materials. Those included the Acacia constricta with Calliandra eriophylla type (8) and the Quercus spp. /Nolina microcarpa type (30). Those two types have minor occurrences on igneous and alluvial parent materials. Only four vegetation types occur two or more times on sandstone parent materials, while fifteen vegetation types are absent or nearly absent from sandstone (see Table 12).

Three vegetation types occur primarily on limestone parent materials. Those include the Mortonia scabrella type (14), the Cercocarpus breviflorus type (23), and the Cowania mexicana type

(26). The Mortonia scabrella type (14) occurs exclusively on limestone parent materials. Only four vegetation types occur two or more times on limestone parent materials, while eighteen, or 72%, of the vegetation types are absent or nearly absent from limestone parent materials. Limestone was observed to be the most restrictive parent material for vegetation types in the study area.

Two vegetation types, the Quercus spp. /Arctostaphylos pungens (without Mimosa biuncifera) type (24) and the Quercus spp. /Arctostaphylos pungens with Mimosa biuncifera type (25) occur primarily on igneous parent materials. Eight vegetation types occur two or more times on igneous parent materials, while eleven types are absent or nearly absent from it (see Table 12).

No vegetation types were observed as occurring primarily on volcanic parent materials. Five vegetation types occur two or more times on it, while seventeen vegetation types are absent or nearly absent from volcanic parent materials (see Table 12).

The six remaining vegetation types, those which do not occur primarily on a single parent material, have a rather diverse range of tolerances and intolerances with respect to various parent materials. The Cercidium microphyllum type (3) occurs on all of the parent materials except volcanic parent materials. The Aloysia wrightii type (12) occurs on all of the parent materials, but especially on limestone. The Prosopis juliflora/Bouteloua spp. type (15) occurs

primarily on volcanic and alluvial parent materials. The *Prosopis juliflora*/*Bouteloua* spp. with *Quercus* spp. type (16) and the *Quercus* spp. /*Mimosa biuncifera* type (27) are both absent or nearly absent from sandstone and limestone parent materials. The *Bouteloua* spp. /*Fouquieria splendens* type (31) occurs primarily on igneous and alluvial parent materials.

Macrorelief

Although an examination of macrorelief data indicates fairly wide ranges of distribution of vegetation types with respect to macrorelief (see Figure 52), it does indicate better relationships than those that exist between the individual species and macrorelief. The best relationships are for the vegetation types occurring on flat topography (macrorelief class 1) and for vegetation types occurring on hilly and mountainous topography (macrorelief classes 4, 5, and 6). Table 13 illustrates the distribution tendencies of vegetation types among macrorelief classes and vegetation types.

Five vegetation types have an affinity for flat topography (macrorelief class 1) but none is restricted to it. The *Sporobolus wrightii* type (21) and the *Larrea tridentata* type (2) occur primarily on smooth flat topography but are also observed on slightly dissected topography (macrorelief classes 1 and 2, respectively). The *Hilaria mutica* type (22), the *Prosopis juliflora* with *Opuntia* spp. (chollas)

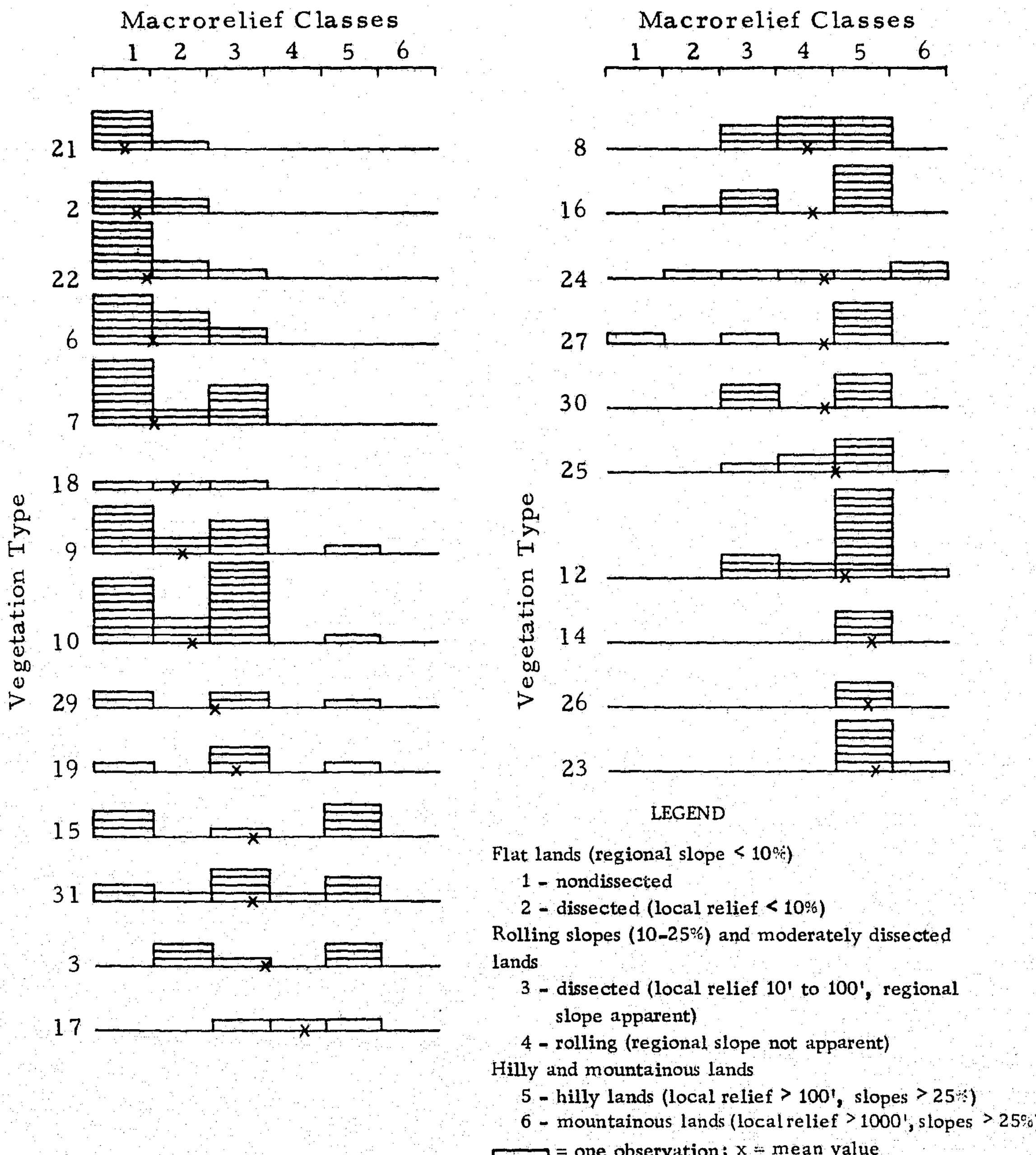


Figure 52. Distribution of vegetation types by macrorelief classes.

C. 3

Table 13. Distribution tendencies of vegetation types among macrorelief classes.

Macrorelief Class 1 (primarily flat)

Vegetation Types: 21, 2, 22, 6, 7

Macrorelief Classes 1, 2, & 3 (flat and dissected)

Vegetation Types: 9, 18, 10, 29, 19

Macrorelief Classes 1, 4, & 5 (flat and hilly)

Vegetation Type: 15

Wide range of Macrorelief Classes

Vegetation Type: 31

Macrorelief Classes 2, 3, & 5 (dissected and hilly)

Vegetation Types: 3, 16, 30

Macrorelief Classes 4, 5, & 6 (primarily hilly or mountainous)

Vegetation Types: 8, 12, 17, 24, 25, 27

Macrorelief Classes 4, 5, & 6 (exclusively hilly or mountainous)

Vegetation Types: 14, 26, 23

type (6), and the Prosopis juliflora (without Opuntia spp. - chollas) type (7) occur principally on smooth flat topography but also, occasionally, on slightly and moderately dissected topography (macrorelief classes 1, 2, and 3, respectively).

Five vegetation types occur primarily on flat and dissected topography (macrorelief classes 1, 2, and 3). Those include the Acacia constricta (without Calliandra eriophylla) type (9), the Bouteloua spp. (without Nolina microcarpa) type (18), the Acacia vernicosa (without Rhus microphylla) type (10), the riparian type (29), and the Bouteloua spp. /Yucca elata type (19).

One vegetation type, the Prosopis juliflora/Bouteloua spp. type (15), occurs on flat and hilly topography (macrorelief classes 1, 4, and 5).

Three vegetation types occur primarily on dissected and hilly topography (macrorelief classes 2, 3, and 5). Those include the Cercidium microphyllum type (3), the Prosopis juliflora/Bouteloua spp. with Quercus spp. type (16), and the Quercus spp. /Nolina microcarpa type (30).

Six vegetation types occur primarily on hilly and mountainous topography (macrorelief classes 4, 5, and 6). They include the Acacia constricta with Calliandra eriophylla type (8), the Aloysia wrightii type (12), the Bouteloua spp. /Nolina microcarpa type (17), the Quercus spp. /Arctostaphylos pungens (without Mimosa biuncifera)

type (24), the Quercus spp./Arctostaphylos pungens with Mimosa biuncifera type (25), and the Quercus spp./Mimosa biuncifera type (27).

Three vegetation types occur exclusively on hilly and mountainous topography (macrorelief classes 4, 5, and 6). They include the Mortonia scabrella type (14), the Cercocarpus breviflorus type (23), and the Cowania mexicana type (26).

While many of the above listed vegetation types occur on a wide variety of macrorelief classes, only one is considered not to have any preference as to type or group of macrorelief types or categories. That is the Bouteloua spp./Fouquieria splendens type (31).

Drainage density

Observations of vegetation types according to drainage density values indicate wide ranges for most vegetation types (see Figure 53). When the vegetation types are ordinated into low, medium, and high drainage densities (< 5.0, $5.0 - 7.2$ and > 7.2 mi./mi.^{2}, respectively), results appear to be more understandable (see Figure 54). Vegetation type distributions according to drainage density fall into seven basic groups of observations (see Table 14).

Four vegetation types are associated primarily with low drainage densities (< 5.0 mi./mi.^{2}). They include the Larrea tridentata type (2), the Cercidium microphyllum type (3), the Mortonia scabrella type (14), and the Sporobolus wrightii type (21).

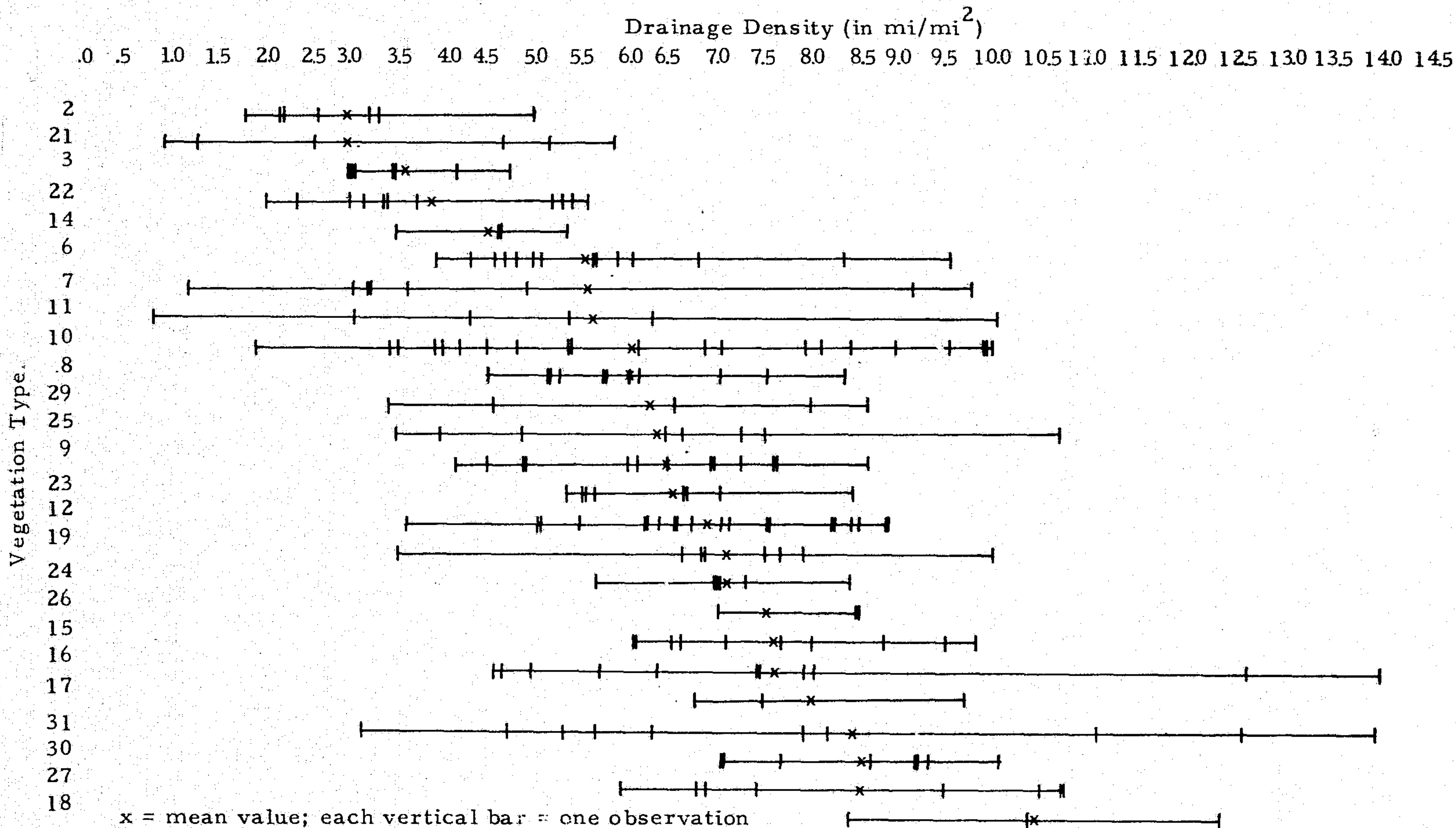


Figure 53. Distribution of vegetation types by drainage density.

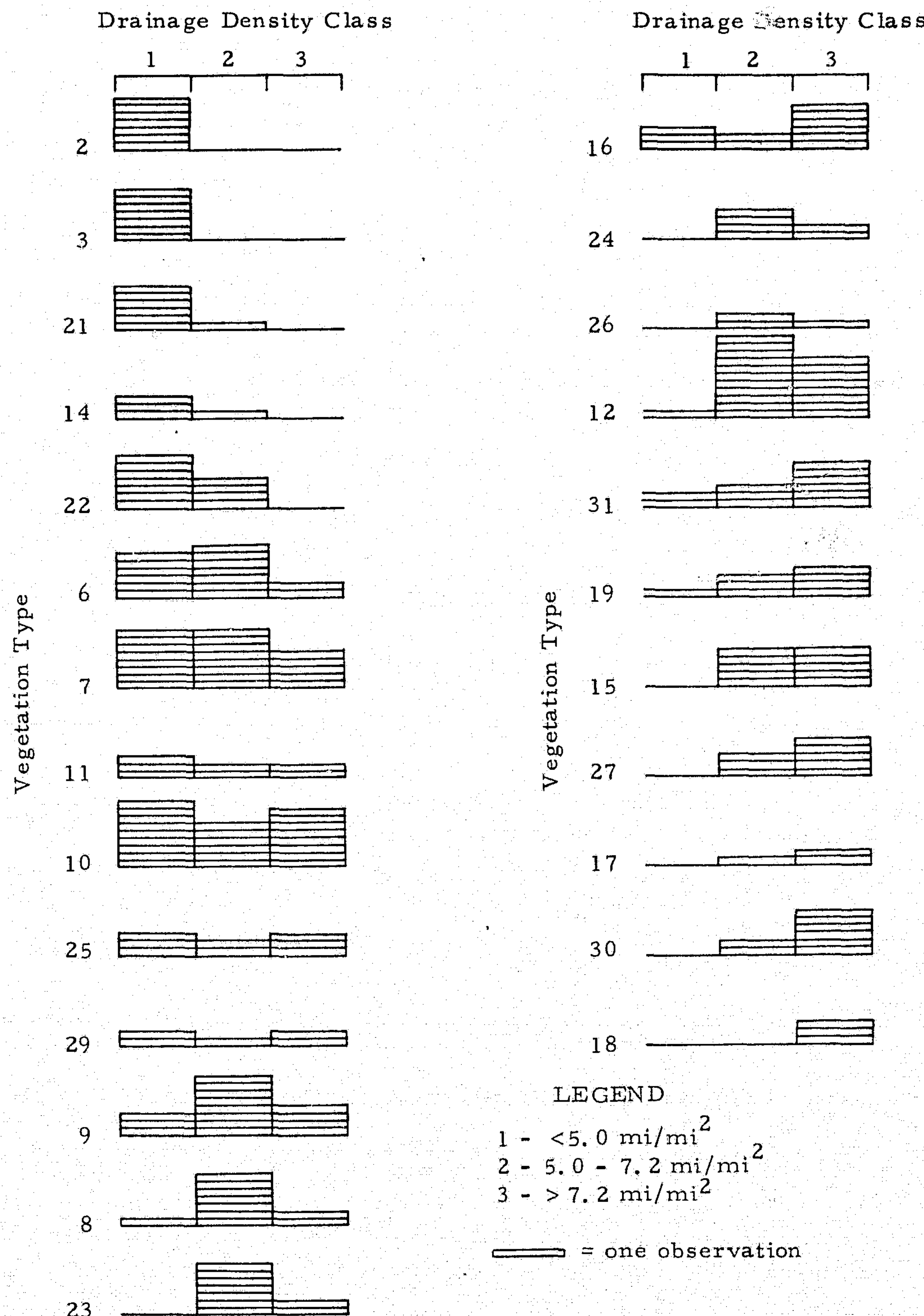


Figure 54. Distribution of vegetation types by drainage density classes.

Table 14. Distribution tendencies of vegetation types among drainage densities.[a]

<u>Low Drainage Density</u> (Dd generally < 5.0 mi./mi.^{2})

Vegetation Types: 2, 3, 14, 21

<u>Low & Middle Drainage Density</u> (Dd generally 2.5-7.0 mi./mi.^{2})

Vegetation Types: 22, 6

<u>Wide Range of Drainage Density</u>

Vegetation Types: 7, 10, 11, 25, 29

<u>Very Wide Range of Drainage Density</u>

Vegetation Types: 16, 31

<u>Middle Drainage Density</u> (Dd generally 4.5-8.0 mi./mi.^{2})

Vegetation Types: 8, 9, 23

<u>Middle & High Drainage Density</u> (Dd generally 5.0-10.0 mi./mi.^{2})

Vegetation Types: 12, 15, 19, 24, 26, 27

<u>High Drainage Density</u> (Dd generally > 7.0 mi./mi.^{2})

Vegetation Types: 17, 30, 18

[a]Drainage density is the ratio of the length of streams in a given area to the area (miles/square miles).

Two vegetation types are associated primarily with low and middle drainage densities (Drainage densities generally 2.5-7.0 mi./mi.^{2}). Those are the Hilaria mutica type (22) and the Prosopis juliflora with Opuntia spp. (chollas) type (6).

Two categories were established for those vegetation types which were observed to occur over a wide range of drainage densities. Those were "wide" and "very wide" ranges of densities. Five vegetation types are considered to occur over a wide range of drainage densities. They include the Prosopis juliflora (without Opuntia spp. - chollas) type (7), the Acacia vernicosa (without Rhus microphylla) type (10), the Acacia vernicosa with Rhus microphylla type (11), the Quercus spp./Arctostaphylos pungens with Mimosa biuncifera type (25), and the riparian type (29). The two vegetation types which are considered to occur over a very wide range of drainage densities are the Prosopis juliflora/Bouteloua spp. with Quercus spp. type (16), and the Bouteloua spp./Fouquieria splendens type (31).

Three vegetation types are considered to be associated with medium drainage densities (Drainage density generally 4.5-8.0 mi./mi.^{2}). They included the Acacia constricta with Calliandra eriophylla type (8), the Acacia constricta (without Calliandra eriophylla) type (9), and the Cercocarpus breviflorus type (23).

Six vegetation types are considered to be associated with middle and high drainage densities (Drainage density generally

$5.0-10.0$ mi./mi.^{2}). They include the Aloysia wrightii type (12), the Prosopis juliflora/Bouteloua spp. type (15), the Bouteloua spp./Yucca elata type (19), the Quercus spp./Arctostaphylos pungens (without Mimosa biuncifera) type (24), the Cowania mexicana type (26), and the Quercus spp./Mimosa biuncifera type (27).

The remaining three vegetation types are primarily associated with high drainage densities (Drainage density generally > 7.0 mi./mi.^{2}). They include the Bouteloua spp./Nolina microcarpa type (17), the Quercus spp./Nolina microcarpa type (30), and the Bouteloua spp. (without Nolina microcarpa) type (18).

Landform

Vegetation types exhibite a wide range of occurrences on different landform types, although they are more narrowly restricted to a given landform than are the individual species. Table 15 illustrates the distribution tendencies of the vegetation types among the landform types. Only the stronger associations between the vegetation types and the landform types are listed in that table.

Four vegetation types are strongly associated with floodplains and terraces in alluvial parent materials. They include the Sporobolus wrightii type (21), the Hilaria mutica type (22), the Quercus spp./Mimosa biuncifera type (27), and the riparian type (29).

Table 15. Distribution tendencies of vegetation types among landform types.

Alluvial Landforms	Vegetation Types
Floodplains	21, 22, 27, 29
Terraces	22, 29
Valley fill	2, 7, 21, 22
Smooth bajadas	6, 7, 9, 11, 15, 21, 22
Side slopes of dissected bajadas	2, 10, 16, 17, 19, 27
Interfluves	2, 3, 6, 8, 9, 18, 19
Non-Alluvial Landforms	
Upper convex slopes	8, 14, 19, 25, 26
Middle or undifferentiated slopes	3, 8, 12, 14, 15, 16, 23, 25, 27, 30
Lower concave slopes	3, 17, 24

Four vegetation types are strongly associated with valley-fill. They include the Larrea tridentata type (2), the Prosopis juliflora (without Opuntia spp. - chollas) type (7), the Sporobolus wrightii type (21), and the Hilaria mutica type (22).

Seven vegetation types are strongly associated with undissected bajadas. They include the Prosopis juliflora with Opuntia spp. (chollas) type (6), the Prosopis juliflora (without Opuntia spp. - chollas) type (7), the Acacia constricta (without Calliandra eriophylla) type (9), the Acacia vernicosa with Rhus microphylla type (11), the Prosopis juliflora/Bouteloua spp. type (15), the Sporobolus wrightii type (21), and the Hilaria mutica type (22).

Six vegetation types are strongly associated with the side slopes of dissected bajadas. They include the Larrea tridentata type (2), the Acacia vernicosa (without Rhus microphylla) type (10), the Prosopis juliflora/Bouteloua spp. with Quercus spp. type (16), the Bouteloua spp. /Nolina microcarpa type (17), the Bouteloua spp. /Yucca elata type (19), and the Quercus spp. /Mimosa biuncifera type (27).

Seven vegetation types are strongly associated with alluvial interfluves. They included the Larrea tridentata type (2), the Cercidium microphyllum type (3), the Prosopis juliflora with Opuntia spp. (chollas) type (6), the Acacia constricta with Calliandra eriophylla type (8), the Acacia constricta (without Calliandra eriophylla) type (9), the Bouteloua spp. (without Nolina microcarpa) type (18),

and the *Bouteloua* spp. /*Yucca elata* type (19).

Five vegetation types are strongly associated with the upper convex hillslopes on non-alluvial parent materials. They include the *Acacia constricta* with *Calliandra eriophylla* type (8), the *Mortonia scabrella* type (14), the *Bouteloua* spp. /*Yucca elata* type (19), the *Quercus* spp. /*Arctostaphylos pungens* with *Mimosa biuncifera* type (25), and the *Cowania mexicana* type (26).

Ten vegetation types are strongly associated with the middle or undifferentiated hillslopes on non-alluvial parent materials. They include the *Cercidium microphyllum* type (3), the *Acacia constricta* with *Calliandra eriophylla* type (8), the *Aloysia wrightii* type (12), the *Mortonia scabrella* type (14), the *Prosopis juliflora*/*Bouteloua* spp. type (15), the *Prosopis juliflora*/*Bouteloua* spp. with *Quercus* spp. type (16), the *Cercocarpus breviflorus* type (23), the *Quercus* spp. /*Arctostaphylos pungens* with *Mimosa biuncifera* type (25), the *Quercus* spp. /*Mimosa biuncifera* type (27), and the *Quercus* spp. / *Nolina microcarpa* type (30).

Three vegetation types are strongly associated with the lower concave hillslopes on non-alluvial parent materials. They included the *Cercidium microphyllum* type (3), the *Bouteloua* spp. /*Nolina microcarpa* type (17), and the *Quercus* spp. /*Arctostaphylos pungens* (without *Mimosa biuncifera*) type (24).

Slope angle

The degree of the relationships between slope angle classes and vegetation types are about the same as between slope angle classes and individual plant species. Figure 55 illustrates the distribution of vegetation types with respect to the slope angle classes. Observations on that figure were later ordinated into low, medium, and high slope angle categories (less than 10%, 10% to 25%, and over 25%, on the average, respectively). Table 16 illustrates the distribution tendencies of the vegetation types among slope angles.

Table 16. Distribution tendencies of vegetation types among slope angles.

Low Slope Angles (averaging less than 10%)	
Vegetation Types:	21, 18, 22 (very low slope angles)
Vegetation Types:	2, 6, 7, 29, 9
Middle Slope Angles (averaging 10-25%)	
Vegetation Types:	11, 10, 19, 31
Vegetation Types:	15, 24, 17, 26, 3
High Slope Angles (averaging over 25%)	
Vegetation Types:	27, 8, 30, 12, 25, 16, 14, 23

Eight vegetation types are considered to be associated primarily with low slope angles. Three types, the Sporobolus wrightii type (21), the Bouteloua spp. (without Nolina microcarpa) type (18), and the Hilaria mutica type (22) are associated with very low slope

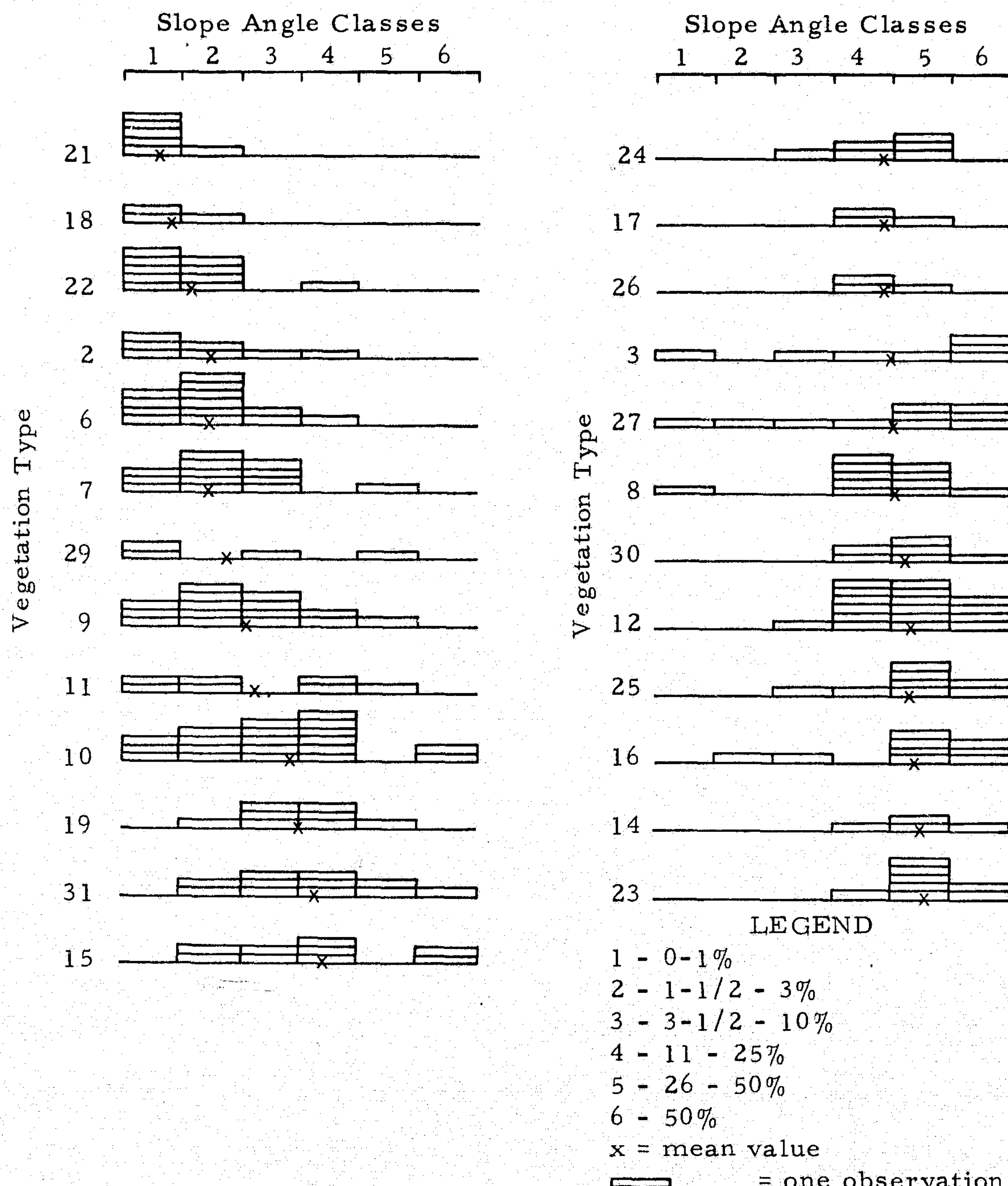


Figure 55. Distribution of vegetation types by slope angle classes.

angles, averaging less than 3%. The other five vegetation types which are associated with low slope angles included the Larrea tridentata type (2), the Prosopis juliflora with Opuntia spp. (chollas) type (6), the Prosopis juliflora (without Opuntia spp. - chollas) type (7), the riparian type (29) and the Acacia constricta (without Calliandra eriophylla) type (9).

Nine vegetation types are considered to be associated primarily with middle slope angles, averaging 10% to 25%. They include the Acacia vernicosa with Rhus microphylla type (11), the Acacia vernicosa (without Rhus microphylla) type (10), the Bouteloua spp. / Yucca elata type (19), the Bouteloua spp. /Fouquieria splendens type (31), the Prosopis juliflora/Bouteloua spp. type (15), the Quercus spp. /Arctostaphylos pungens (without Mimosa biuncifera) type (24), the Bouteloua spp. /Nolina microcarpa type (17), the Cowania mexicana type (26), and the Cercidium microphyllum type (3).

The remaining eight vegetation types are considered to be associated with high slope angles, averaging over 25%. They include the Quercus spp. /Mimosa biuncifera type (27), the Acacia constricta with Calliandra eriophylla type (8), the Quercus spp. /Nolina microcarpa type (30), the Aloysia wrightii type (12), the Quercus spp. / Arctostaphylos pungens with Mimosa biuncifera type (25), the Prosopis juliflora/Bouteloua spp. with Quercus spp. type (16), the Mortonia scabrella type (14), and the Cercocarpus breviflorus type (23).

Slope aspect

Better relationships exist between vegetation types and slope aspect than between individual plant species and slope aspect. Figure 56 illustrates the distribution of vegetation types according to slope aspect. Those observations were later ordinated into three general aspect classes; southerly, little aspect preference or primarily level, and northerly, see Table 17.

Six vegetation types are considered to have an association with southerly aspects. They include (in order from the most southerly) the Bouteloua spp. /Fouquieria splendens type (31), the Cercidium microphyllum type (3), the Acacia constricta with Calliandra eriophylla type (8), the Quercus spp. /Arctostaphylos pungens with Mimosa biuncifera type (25), the Bouteloua spp. /Yucca elata type (19), and the Cowania mexicana type (26).

Eleven vegetation types occur on sites which are fairly level, or whose slope aspect shows little preference to north or south. They include the Prosopis juliflora/Bouteloua spp. type (15), the Acacia constricta (without Calliandra eriophylla) type (9), the Mortonia scabrella type (14), the Prosopis juliflora with Opuntia spp. (chollas) type (6), the Aloysia wrightii type (12), the Acacia vernicosa (without Rhus microphylla) type (10), the Hilaria mutica type (22), the Larrea tridentata type (2), the Prosopis juliflora (without Opuntia spp. -

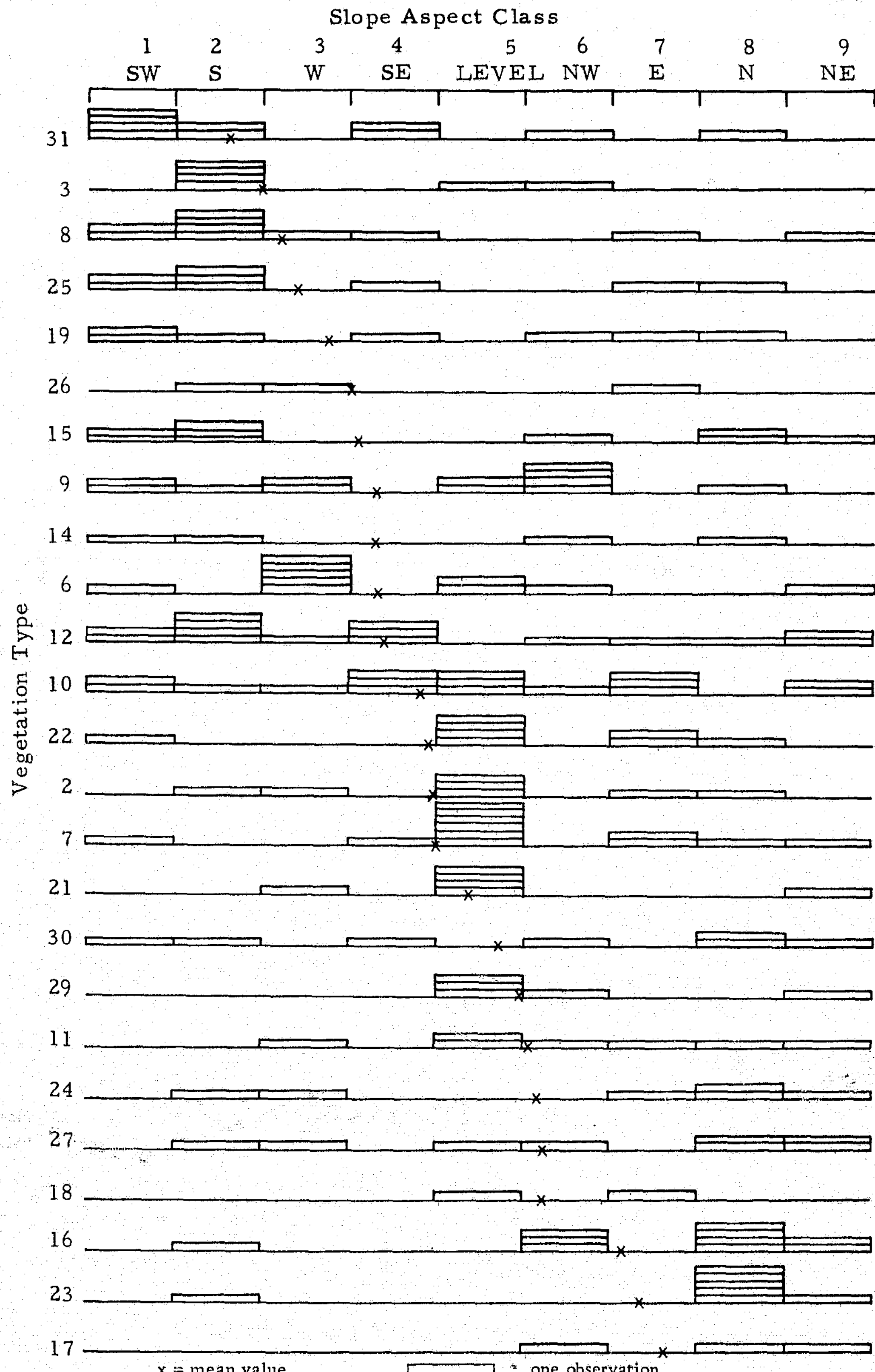


Figure 56. Distribution of vegetation types by slope aspect.

chollas) type (7), the Sporobolus wrightii type (21), and the Quercus spp. /Nolina microcarpa type (30).

The remaining eight vegetation types are primarily associated with northerly aspects. They include the riparian type (29), the Acacia vernicosa with Rhus microphylla type (11), the Quercus spp. / Arctostaphylos pungens (without Mimosa biuncifera) type (24), the Quercus spp. /Mimosa biuncifera type (27), the Bouteloua spp. (without Nolina microcarpa type (18), the Prosopis juliflora/Bouteloua spp. with Quercus spp. type (16), the Cercocarpus breviflorus type (23), and the Bouteloua spp. /Nolina microcarpa type (17).

It appears that the vegetation types are better correlated to northerly aspects than to southerly ones; see Figure 56.

Table 17. Distribution tendencies of vegetation types among slope aspect classes.

Southerly Aspects	
Vegetation Types:	31, 3, 8, 25, 19, 26
Little aspect preference or primarily level	
Vegetation Types:	15, 9, 14, 6, 12, 10, 22, 2, 7, 21, 30
Northerly Aspects	
Vegetation Types:	29, 11, 24, 27, 18, 16, 23, 17

Solar radiation index

The final terrain or environmental variable to be discussed in relation to vegetation types is solar radiation index. This together with elevation is a good moisture correlate. Figure 57 illustrates the range of occurrences of the vegetation types according to classes of the solar radiation index. That distribution was ordinated into groups of low, average, and high distribution tendencies (see Table 18).

Table 18. Distribution tendencies of vegetation types among solar radiation index values.

Low Solar Radiation Index

Vegetation Types: 17, 23, 16 (very low solar radiation index)
Vegetation Types: 27, 11, 24

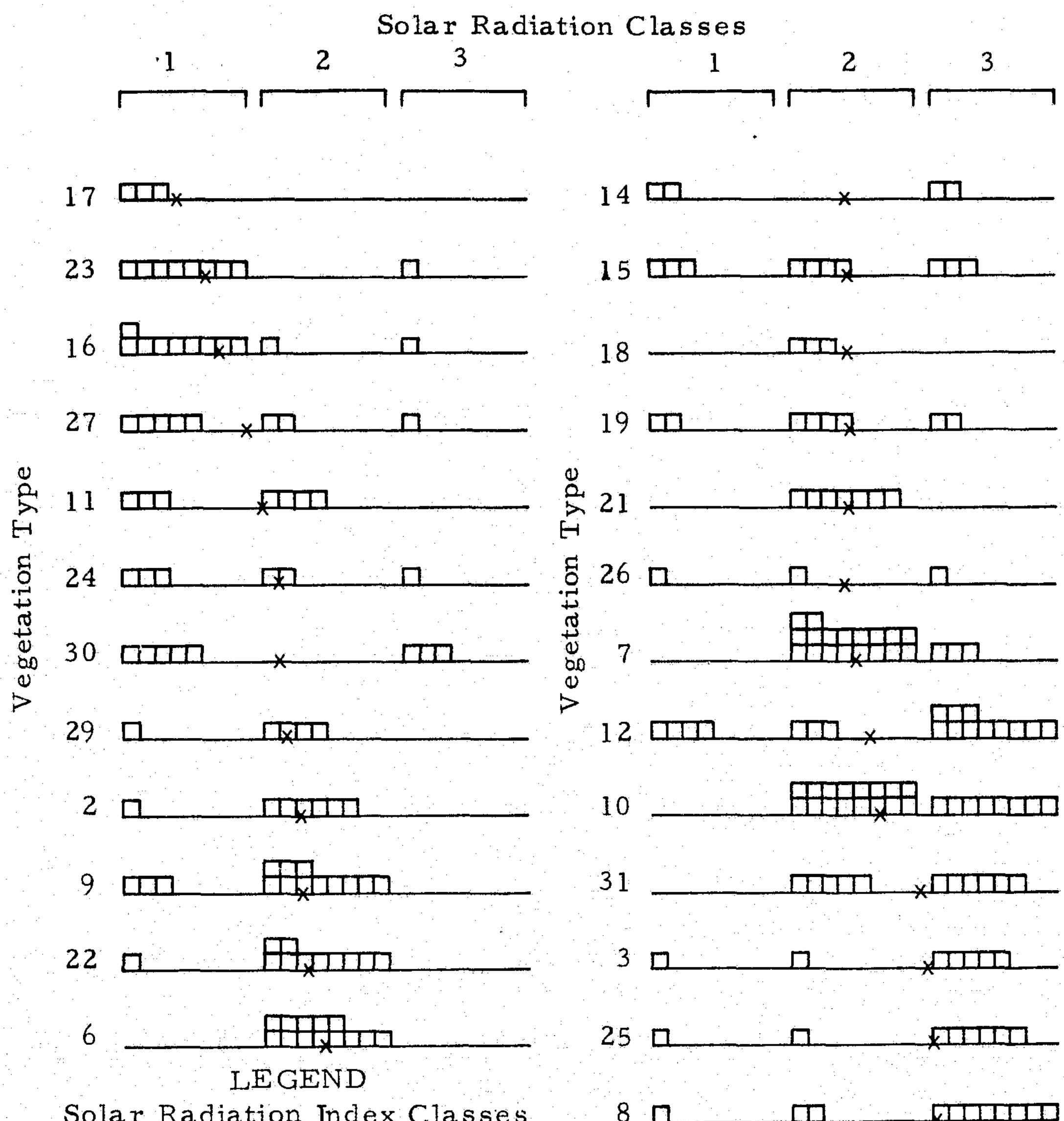
Average Solar Radiation Index

Vegetation Types: 30, 29, 2, 9, 22, 6, 14, 15, 18, 19, 21, 26

High Solar Radiation Index

Vegetation Types: 7, 12, 10, 31
Vegetation Types: 3, 25, 8 (very high solar radiation index)

Six vegetation types occur primarily on sites having a low solar radiation index. They include the Bouteloua spp. /Nolina microcarpa type (17), the Cercocarpus breviflorus type (23), and the Prosopis juliflora/Bouteloua spp. with Quercus spp. type (16), which are all closely correlated to very low values of the solar radiation index.



LEGEND

Solar Radiation Index Classes

1 = SR index of < 51

2 = SR index of 51-54

3 = SR index of > 54

x = mean value

□ = one observation

Figure 57. Distribution of vegetation types by solar radiation index classes.

Other vegetation types which are associated with low solar radiation include the Quercus spp. /Mimosa biuncifera type (27), the Acacia vernicosa with Rhus microphylla type (11), and the Quercus spp. / Arctostaphylos pungens (without Mimosa biuncifera) type (24).

Seven vegetation types occur primarily on sites having a high solar radiation index. Three, which are associated with very high values include the Cercidium microphyllum type (3), the Quercus spp. /Arctostaphylos pungens with Mimosa biuncifera type (25), and the Acacia constricta with Calliandra eriophylla type (8). The remaining four types which are associated with high solar radiation include the Prosopis juliflora (without Opuntia spp. - chollas) type (7), the Aloysia wrightii type (12), the Acacia vernicosa (without Rhus microphylla) type (10), and the Bouteloua spp. /Fouquieria splendens type (31).

The remaining twelve vegetation types are not strongly associated with either high or low indices of solar ratiation.

Analysis of the relationships between vegetation types and terrain variables using stepwise discriminant analysis

In the stepwise discriminant analysis programs that analyzed the relationships between vegetation types and terrain variables, the vegetation types were considered as groups and the terrain variables

as "variables". All terrain variables were considered together and analyzed to assess the groups of vegetation types. The stepwise discriminant analysis program determined the order in which the terrain variables could discriminate or differentiate the groups of vegetation types. The vegetation types, themselves, are then classified or plotted in a two-way table to show the relative separation among types. It is to be remembered that the program analyzes only numerical values of the variables. Hence, if a particular variable is non-parametric (for example, parent material), its association with vegetation types will not be as accurately determined as would the association between more highly parametric variables (such as elevation).

The first program employing stepwise discriminant analysis to examine relationships between terrain variables and vegetation types was a run which employed only six preliminary vegetation types. Those preliminary vegetation types were determined prior to the vegetation classification which resulted in thirty-one vegetation types being identified in the study area. It was decided that the six types would be chosen from among the three widely separate physiognomic types in the study area region: grassland, shrubland, and woodland. Within each of these three physiognomic types, two vegetation units were chosen. The six preliminary vegetation types

were: from the grassland, a Hilaria mutica type and a Sporobolus wrightii type; from the shrubland, a Fouquieria splendens type and a Mortonia scabrella type; and from the woodland type, a Quercus emoryi type and a Juniperus deppeana type. Those six vegetation types do not coincide with any of the thirty-one vegetation types determined by our vegetation classification.

The results of the run indicated a nearly perfect separation of the three physiognomic types on the basis of the terrain variables employed. Figure 58 illustrates the scatter diagram produced by the program and indicates the separation of the physiognomic types.

The terrain variables listed in order of declining ability to discriminate the six vegetation types were macrorelief, drainage density, elevation, solar radiation index, slope angle, parent material, landform type, and slope aspect. In general, the Sporobolus wrightii type and the Hilaria mutica type occurred on sites having low elevation, low drainage density, and low macrorelief class (therefore a tendency toward flat topography). The Fouquieria splendens type and the Mortonia scabrella type tended to occur at middle elevations, medium drainage densities, and medium to high macrorelief class (a tendency toward dissected and hilly topography). The Quercus emoryi type and the Juniperus deppeana type had a tendency to occur on sites with high elevations, high drainage densities, and high macrorelief class (a tendency toward hilly to mountainous topography).

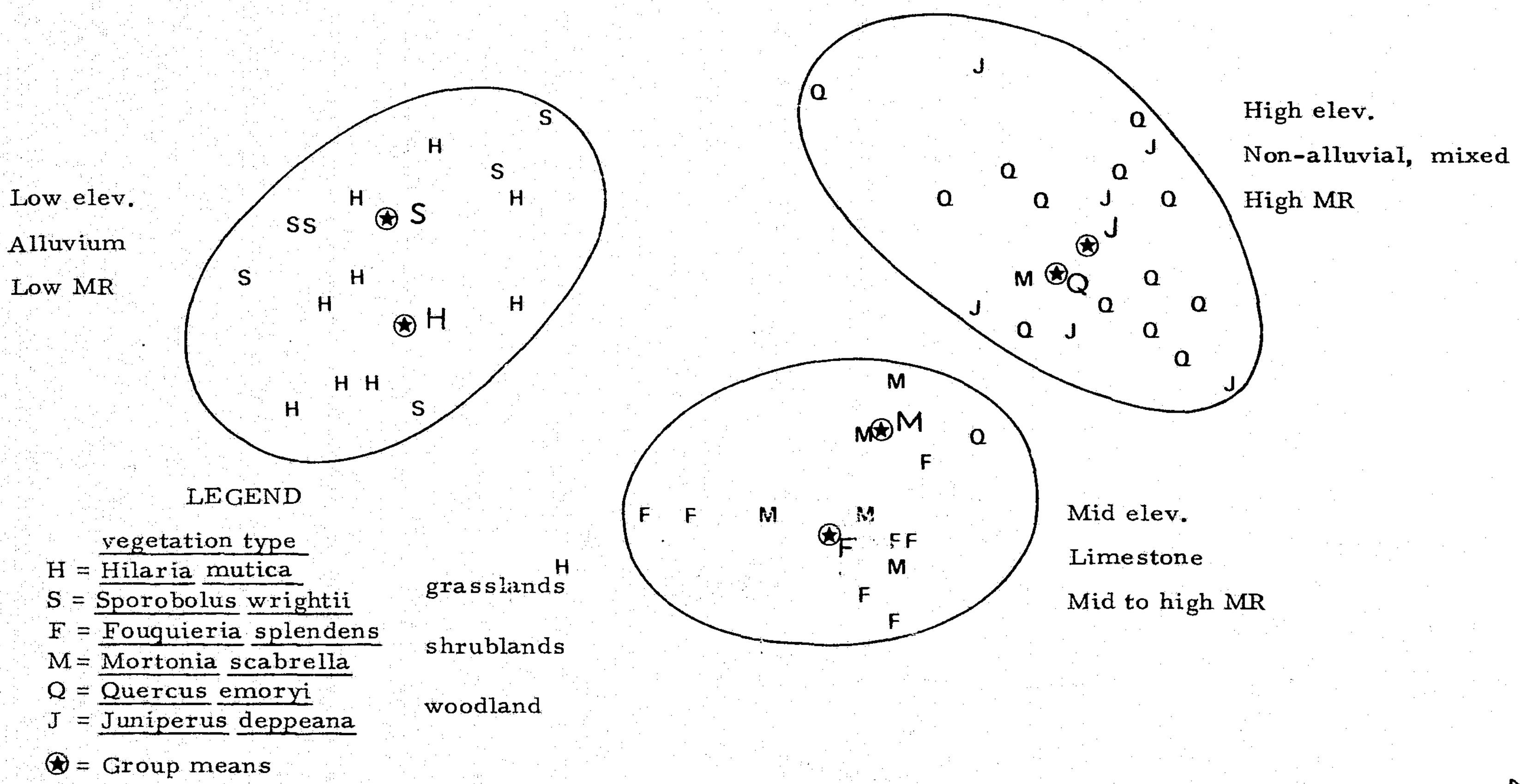


Figure 58. A scatter diagram of the first two canonical variates where groups are from eight vegetation units and variables are terrain variables.

In this particular analysis, stepwise discriminant analysis identifies for each vegetation type an array of values of the terrain variables that best correlates as a set with that particular vegetation type. The program then analyzes the terrain variables of a given observation (or field sample site; there were 51 in this run) and then classifies or identifies that observation into the vegetation type with which it best correlates on the basis of the values of terrain variables at that site. If the observation is placed into the vegetation type which was identified as such by field observation (and then subsequent classification), then a correct match was made. An observation can, however, be placed into a vegetation type other than the one identified by the field observation. The program perfectly discriminated the grassland types from the other two physiognomic types (as Figure 58 illustrates). In fact, of the six Sporobolus wrightii type occurrences, only one was considered to be more like the Hilaria mutica type than the Sporobolus wrightii type in terms of its terrain variables. Based on distance measures of the ten Hilaria mutica type occurrences, two were considered to be more like the Sporobolus wrightii type than the Hilaria mutica type.

Of the fourteen shrubland occurrences, one was more like a woodland type than a shrubland type; while of the twenty-one woodland occurrences, two were more like a shrubland type than a woodland type in terms of their respective terrain variables. Of the seven

Fouquieria splendens type occurrences, one was more like a Mortonia scabrella type than a Fouquieria splendens type. Of the seven observations placed into the Mortonia scabrella type, two were more like a Fouquieria splendens type, and one was more like a Juniperus deppeana type than a Mortonia scabrella type in terms of the terrain variables observed for the type. Of the fifteen Quercus emoryi type occurrences, one was more like a Fouquieria splendens type than a Quercus emoryi type, one was more like a Mortonia scabrella type than a Quercus emoryi type, and two were more like the Juniperus deppeana type than the Quercus emoryi type in terms of observed terrain variables. Finally, among the six Juniperus deppeana type occurrences, only one was more like another type (the Quercus emoryi type) than like the Juniperus deppeana type.

This preliminary analysis indicated the efficacy of the method (Mouat, 1972). The vegetation types reported were not the same as the types arrived at by our more extensive vegetation classification, but they nevertheless illustrated the use of the program.

The real test in using stepwise discriminant analysis in the study of the relationships between terrain variables and vegetation types came when all vegetation types and all observations were included. In those analyses, elevation and macrorelief were the best discriminants of the vegetation types. Elevation had nearly twice the F statistic value that macrorelief had, indicating the discriminating

ability of that variable. The next best discriminant was the incident solar radiation index. That was followed closely by drainage density and then parent material. The poorest discriminants were landform type, slope angle, and slope aspect. On another run using all vegetation types, it was decided to delete the landform types because of their being non-parametric. Figure 59 illustrates the scatter diagram produced by the program and indicates the separation of the twenty-five vegetation types by the terrain variables.

Results of the stepwise discriminant analysis using all terrain variables show that of the 242 observations (field sample sites) included in an analysis of twenty-five vegetation types, 120 were placed by the program into the correct vegetation type from the standpoint of the terrain variables. The analysis neither "agrees" nor "disagrees" with the vegetation classification. It does, however, point to the degree of cohesion within and among groups from the standpoint of terrain variable interaction.

The classification can be considered in its two-way format as follows: it determines which observations (field sample sites) placed by the vegetation classification into a particular vegetation type have terrain variables most like that vegetation type or most like some other type.

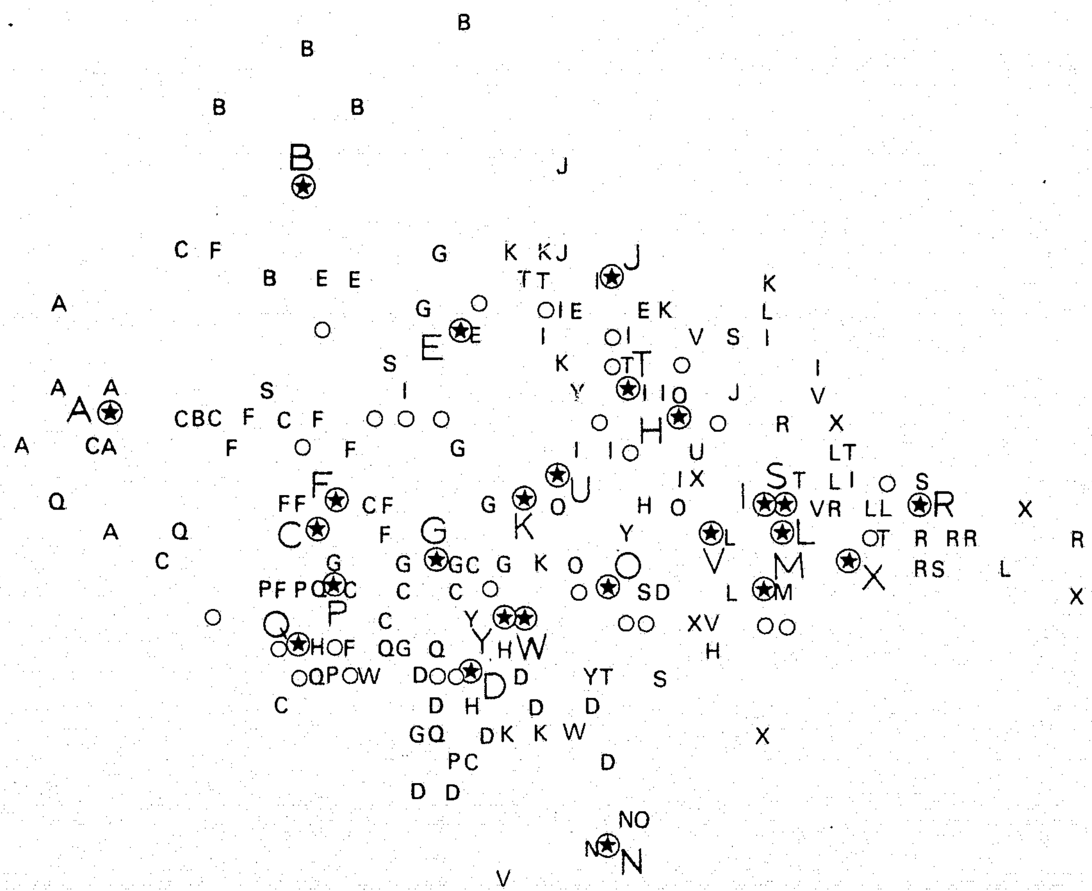
Figure 60 summarizes the classification (or identification) performed by the program; it is a two-way matrix. On the left side of the matrix is the floristically-defined vegetation types. Along the top of the matrix are listed the analogous vegetation type classes.

Figure 59. A scatter diagram of the first two canonical variates where groups are from twenty-five vegetation types and variables are terrain variables.

Symbol	Vegetation types names (abbreviated)	Identifier Number
A	Larrea tridentata with Prosopis juliflora	(2)
B	Cercidium microphyllum	(3)
C	Prosopis juliflora with Opuntia spp. (cholla)	(6)
D	Prosopis juliflora(without Opuntia spp. - cholla)	(7)
E	Acacia constricta with Calliandra eriophylla	(8)
F	Acacia constricta (without Calliandra eriophylla	(9)
G	Acacia vernicosa (without Rhus microphylla)	(10)
H	Acacia vernicosa with Rhus microphylla	(11)
I	Aloysia wrightii	(12)
J	Mortonia scabrella	(14)
K	Prosopis juliflora/Bouteloua spp.	(15)
L	Prosopis juliflora/Bouteloua spp. with Quercus spp.	(16)
M	Bouteloua spp. /Nolina microcarpa	(17)
N	Bouteloua spp. (without Nolina microcarpa)	(18)
O	Bouteloua spp. /Yucca elata	(19)
P	Sporobolus wrightii	(21)
Q	Hilaria mutica	(22)
R	Cercocarpus breviflorus	(23)
S	Quercus spp. /Arctostaphylos pungens (without Mimosa biuncifera)	(24)
T	Quercus spp. /Arctostaphylos pungens with Mimosa biuncifera	(25)
U	Cowania mexicana	(26)
V	Quercus spp. /Mimosa biuncifera	(27)
W	riparian	(29)
X	Quercus spp. /Nolina microcarpa	(30)
Y	Bouteloua spp. /Fouquieria splendens	(31)

⊛ Mean values (e. g. A ·)

O Overlap of values



Program-derived Terrain Variable-defined Vegetation Types

Floristically-Defined Vegetation Types	Latr$_1$	Cemi$_1$	Opun$_1$	Prju$_1$	Caer$_1$	Acco$_1$	Acve$_1$	Rhmi$_1$	Alwr$_1$	Mosc$_1$	PrBo$_1$	PrBQ$_1$	BoNo$_1$	Bout$_1$	BoYu$_1$	Spwr$_1$	Himu$_1$	Cebr$_1$	QuAr$_1$	QAMi$_1$	Come$_1$	QuMi$_1$	Ripa$_1$	QuNo$_1$	BoFo$_1$	(total number of floristically-defined type stands)
2 = Latr	7																									7
3 = Cemi		5	1		1																					7
6 = Opun	2	1	6	2											1	2	1									15
7 = Prju			1	11											2	2	1		1						3	21
8 = Caer					8		2													1						11
9 = Acco		1	2	1		10																1				15
10 = Acve		1		4		1	8				1			1	2	2	1			1					2	24
11 = Rhmi				3				1					1				1								1	7
12 = Alwr					1	2	1		5	1								1		3	1	4		1		20
14 = Mosc										4																4
15 = PrBo				2	1						1	2			2							1			1	10
16 = PrBQ							1					7			1							1		1		11
17 = BoNo												1	1						1							3
18 = Bout														3												3
19 = BoYu				1				1				1	1		2						1				1	8
21 = Spwr							1									5							1			7
22 = Himu			1	1		2										1	6									11
23 = Cebr									1			1						7								9
24 = QuAr												1	1						2	1	1					6
25 = QAMi								1	1			1								4				1		8
26 = Come																					3					3
27 = QuMi														1						1	1	5				8
29 = Ripa										1						1			1				2			5
30 = QuNo												1	2						1	1				3		8
31 = BoFo				1	2	1			1		1				1										4	11
(total number of program-derived terrain variable-defined type stands)	9	8	11	26	13	16	13	3	8	6	3	15	6	5	11	13	10	8	6	12	7	12	3	6	12	

Figure 60. A two-way classification matrix of floristically-defined vegetation types and terrain variable-defined vegetation types.

However, instead of their being floristically defined, they are defined by the set of terrain variables which were observed to occur for those sites that comprise the type. The "program-derived terrain variable-defined vegetation types" represent an ordination of the vegetation types based upon the set of terrain variables which are identified with each vegetation type. Thus, field sites (or observations) listed below each of the program-derived terrain variable-defined vegetation types indicate that a site (or observation) has terrain variable associations more closely aligned with a given floristically-defined vegetation type than with any other vegetation type. The chief criterion for "closeness" is a measure of Mahalanobis distance as defined and determined by the stepwise discriminant analysis. The number of field sites placed in the boxes along the diagonal of the matrix indicate observations that have been classified the same way by the two different methods. Field sites which are not listed on the diagonal indicate that a program-derived terrain variable-defined vegetation type is more like some other floristically-defined vegetation type than like a vegetation type derived by the program from terrain variable classes. Field sites (or observations) placed on the same horizontal line as a floristically-defined vegetation type belong to that vegetation type, thus there are seven sites belonging to vegetation type 2 = Latr. The floristic classification indicates that seven stands (similar to observations) were placed in that type

(that is, 2 = Latr). The program-derived terrain variable-defined classification indicates that all seven stands are most like the program-derived terrain variable-defined vegetation type $Latr_1$ with which it is analogous. However, when the vegetation types are considered from the standpoint of the terrain variables, two stands are classified which were floristically defined as in vegetation type 6 = Opun, and seven stands were correctly placed into the type 2 = Latr. Using floristically-defined vegetation types to determine terrain variable classes or associations of stands, results using the Larrea tridentata type (2 = Latr) as an example would be most favorable.

As a second example, consider the Aloysia wrightii type (12 = Alwr). Twenty stands were floristically identified as belonging to the type. The program-derived terrain variable-defined classification indicates that only five stands are most like the terrain variable-defined type 12 = $Alwr_1$. Fifteen other stands are more like classification units more like other terrain variable-defined vegetation types. From the standpoint of floristics, five stands were most like the floristically defined vegetation type 12 = Alwr, while three other stands were more like some other floristically-defined vegetation type. Those eight stands had a terrain variable association that coincided with the terrain variable-defined vegetation type $Alwr_1$.

VI. SUMMARY AND CONCLUSIONS

Relationships between vegetation and terrain variables were studied in an area comprising approximately 4, 000 square miles in southeastern Arizona encompassing a wide variety of semiarid landforms and vegetation. 250 field sample sites were selected within this area and were used in the analyses of relationships between vegetation and eight terrain variables. Analyses considered the flora of the area as well as 31 vegetation types. The eight terrain variables consisted of elevation, parent materials, macrorelief, landform type, drainage density, slope angle, slope aspect, and solar radiation index.

The study indicated relationships between the eight terrain variables and plant species on the one hand and the 31 vegetation types on the other. Certain plant species are better than others for differentiating or discriminating groups of specified terrain variables. Certain terrain variables are better than others for differentiating or discriminating groups of vegetation types. Stepwise discriminant analysis has been shown to be a useful tool in plant ecological studies.

It is most important to realize that the terrain variables studied are relatively photo-interpretable. Important environmental considerations including climate and chemical and physical

characteristics of soil were not included in the analyses. More positive relationships between vegetation and the total environment would undoubtedly be found if additional environmental variables were employed, or, for that matter, if those studied were interpreted with respect to climate.

Conclusions Regarding Plant Species and Terrain Variables

Plant species that appear to be closely correlated with elevation include 1) Opuntia fulgida, Cercidium floridum, C. microphyllum, and Cereus giganteus, all of which occur primarily in the lower elevations (that is, below 3, 800 feet); 2) Sporobolus airoides, and Flourensia cernua, which occur primarily in the middle elevations, 4, 000 feet to 4, 800 feet; and 3) Pinus cembroides, Cowania mexicana, and Cercocarpus breviflorus, which occur primarily only at higher elevations, above 5, 100 feet. Several species, notably Prosopis juliflora, Opuntia spinosior, Opuntia phaeacantha, and Fouquieria splendens, occur throughout a wide range of elevations, primarily between 3, 000 feet and 5, 500 feet. The reader is referred to Figure 40 which shows the distribution range by elevation of species.

Plant species are found to be closely associated with parent materials. Cercocarpus breviflorus, Aloysia wrightii, and Mortonia scabrella are clearly defined by floristic analysis as well as by

results of the stepwise discriminant analysis as being closely associated with limestone parent materials. *Aloysia wrightii*, while observed to occur over a wide variety of parent materials, is included as an indicator of limestone on account of its much higher cover values on limestone than on the other parent materials. *Agave schottii* is considered to be a good indicator of limestone and of igneous parent materials. *Yucca elata* and *Cercidium microphyllum* are nearly limited in their occurrence to alluvial parent materials and can be considered as good indicators of alluvium.

Plant species with relationships to macrorelief include *Sporobolus airoides* and *Hilaria mutica*, which are closely associated with flat topography (macrorelief class 1). Several species, including *Arctostaphylos pungens*, *Agave schottii*, *Aloysia wrightii*, *Mortonia scabrella*, and *Cercocarpus breviflorus*, are closely associated with hilly and mountainous topography (macrorelief classes 4, 5, and 6). Most species, however, are not closely associated with macrorelief.

Species relationships with drainage density, likewise, are not particularly close. Most species have distributions over fairly wide ranges of drainage density. Exceptions include *Juniperus monosperma*, *Cercocarpus breviflorus*, *Quercus oblongifolia*, *Mimosa biuncifera*, and *Nolina microcarpa*, which occur predominantly on sites with high drainage densities, and *Flourensia cernua*, *Larrea tridentata*, *Opuntia fulgida*, *Haplopappus tenuisectus*, *Hilaria mutica*,

and Mortonia scabrella, which occur predominantly on low drainage density sites. Drainage density is considered to represent a close correlation with elevation since low drainage densities are strongly related to low elevations, and high drainage densities are strongly related to high elevations.

Species tend to occur over a fairly wide variety of landform types. Aloysia wrightii, Cercocarpus breviflorus, and Mortonia scabrella, are generally restricted to non-alluvial hillslopes. Pinus cembroides occurs predominantly on the lower concave hillslopes on non-alluvial parent materials. Acacia vernicosa, Haplopappus tenuisectus, and Yucca elata tend to occur only on smooth alluvial surfaces. Most other species occur over a fairly wide range of alluvial surfaces.

Some species are closely related to slope angle. Sporobolus airoides, Haplopappus tenuisectus, Cercidium floridum, Hilaria mutica, and Yucca elata can be considered as good indicators of low slope angles. Cowania mexicana, Juniperus monosperma, Agave schottii, Pinus cembroides, Rhus choriophylla, Mortonia scabrella, and Cercocarpus breviflorus occur primarily on slopes with moderate angles. Aloysia wrightii, Dasylirion wheeleri, Nolina microcarpa, Quercus emoryi, Q. oblongifolia, and Mimosa dysocarpa, occur predominantly on the steepest slopes. The remaining species occur over a fairly wide range of slope angles.

Species do not relate well to slope aspect. The best species for discriminating slope aspect classes were *Cercidium microphyllum*, *Calliandra eriophylla*, and *Cereus giganteus*, for southerly aspects, and *Quercus oblongifolia*, *Pinus cembroides*, and *Juniperus monosperma* for northerly aspects. Those species which relate well to slope aspect also correlate well with incident solar radiation index.

Table 19 illustrates the general relationships of forty-one species to eight terrain variables. The figure represents a subjective summary of the relationships. Excellent or close relationships are indicated by a "5" and the poorest or least close are indicated by a "1". Numbers in between represent relationships ranging from good to fair. While many species exhibit little or no correlation with many of the terrain variables studied, most bear a strong relationship to at least one or two.

Conclusions Regarding Vegetation Types and Terrain Variables

Vegetation types were determined from data collected from several hundred observations of floristic characteristics within the study area. Twenty-five vegetation types of the thirty-one identified have frequencies of three or more among the 250 sample sites considered.

Vegetation type amplitudes with regard to terrain variables are found to be narrower in most instances than the amplitudes for

Table 19. Summary of relationships between species and terrain variables based upon subjective evaluation of the data available. Numerican entries 1 through 5 correspond respectively to ratings of poor, fair, moderate, goo, and excellent relationship.

Species	Elevation	Parent Material	Slope Aspect	Slope Angle	Solar Radiation	Landform	Macro-relief	Drainage Density	Summary
Acacia constricta	2	2	1	3	1	3	1	2	2
Acacia vernicosa	3	5	2	2	1	2	3	1	2+
Agave palmeri and/or parryi	4	3	2	4	1	4	5	2	3+
Agave schottii	4	4	3	4	2	5	5	1	3+
Aloysia wrightii	2	4	1	4	1	4	5	3	3
Arctostaphylos pungens	4	4	2	4	1	3	4	2	3+
Bouteloua curtipendula	3	2	2	3	1	3	3	3	2+
Bouteloua rothrockii	3	3	2	2	1	1	2	1	2
Calliandra eriophylla	3	1	3	3	3	2	3	2	2
Cercidium floridum	4	5	2	3	1	3	3	3	3+
Cercidium microphyllum	4	2	5	2	3	3	1	4	3
Cercocarpus breviflorus	5	5	4	4	3	5	5	4	4+
Cereus giganteus	4	3	3	1	3	3	2	4	3
Condalia lycioides	2	2	3	3	2	2	2	2	2
Cowania mexicana	5	5	2	4	4	5	5	4	4+
Dasylirion wheeleri	3	4	3	4	2	4	5	3	3+
Ferocactus wislizenii	3	2	4	3	3	2	2	2	3-
Flourensia cernua	4	4	1	2	2	4	2	1	3-
Fouquieria splendens	2	2	1	2	3	2	2	2	2
Haplopappus tenuisectus	2	2	1	4	3	3	3	1	2+
Hilaria mutica	3	4	1	4	3	4	4	3	3+
Juniperus deppeana	3	2	4	3	4	3	3	3	3+
Juniperus monosperma	3	4	4	4	5	3	4	3	4-
Larrea tridentata	2	4	1	1	2	2	2	2	2
Mimosa biuncifera	3	3	3	3	2	2	3	1	3-
Mimosa dysocarpa	4	1	3	5	4	4	4	3	3+
Mortonia scabrella	4	5	3	5	4	5	5	5	4+
Nolina microcarpa	4	3	3	4	3	2	5	3	4-
Opuntia fulgida	1	4	1	3	1	1	2	2	2
Opuntia phaeacantha	1	1	1	3	1	1	1	2	1

ORIGINAL PAGE IS OF POOR QUALITY

Table 19. (continued).

Species	Elevation	Parent Material	Slope Aspect	Slope Angle	Solar Radiation	Landform	Macrorelief	Drainage Density	Summary
Opuntia spinosior	1	1	1	2	1	2	1	1	1
Parthenium incanum	4	2	3	3	3	2	4	1	3-
Pinus cembroides	5	2	5	4	4	5	4	5	4+
Prosopis juliflora	2	1	1	3	1	2	1	1	1+
Quercus arizonica	4	2	3	2	3	3	4	3	3
Quercus emoryi	4	4	4	4	3	3	4	4	4-
Quercus oblongifolia	4	2	5	5	5	3	4	2	3+
Rhus choriophylla	4	4	4	4	2	4	5	4	4
Sporobolus airoides	5	5	5	5	5	5	5	5	5
Yucca elata	3	5	1	4	2	3	4	2	3+

individual species. With a few exceptions (for example the Aloysia wrightii type - 12) vegetation types display neatly defined elevational ranges. Examples of vegetation types with restricted elevation ranges include the Larrea tridentata type (2), the Cercidium microphyllum type (3), the Prosopis juliflora/Bouteloua spp. type (15), the Acacia vernicosa with Rhus microphyllum type (11), the Bouteloua spp. Nolina microcarpa type (15), the Bouteloua spp. (without Nolina microcarpa) type (18), the Cowania mexicana type (26), and the Cercocarpus breviflorus type (23).

Vegetation types are found to have quite close associations with parent materials. Nineteen vegetation types occur primarily on one parent material. Twelve vegetation types occur predominantly on alluvial parent materials of which five occur exclusively on it. Two vegetation types occur primarily on sandstone parent materials, three types occur primarily on limestone, and two types occur primarily on igneous and metamorphic parent materials. No vegetation types occur predominantly on volcanic parent materials.

The most positive relationships between vegetation types and macrorelief are for those types which occur on flat topography and for those types which occur primarily on hilly and mountainous topography (macrorelief classes 4, 5, and 6). The Sporobolus wrightii type (21) and the Larrea tridentata type (2) are examples of vegetation types which occur predominantly on flat topography

(macrorelief class 1). Examples of the vegetation types which occur extensively on hilly and mountainous topography include the Mortonia scabrella type (14), the Cowania mexicana type (26), and the Cercocarpus breviflorus type (23).

Vegetation types do not appear to have particularly strong relationships with drainage density. Four vegetation types: the Larrea tridentata type (2), the Cercidium microphyllum type (3), the Mortonia scabrella type (14), and the Sporobolus wrightii type (21), occur mainly on low drainage densities. Three vegetation types: the Bouteloua spp./Nolina microcarpa type (17), the Quercus spp./ Nolina microcarpa type (30), and the Bouteloua spp. (without Nolina microcarpa) type (18), occur primarily on the high drainage densities. The remaining eighteen vegetation types have scattered relationships with respect to drainage density.

The vegetation types exhibit a wide range of occurrences on landform types, although they have closer relationships with landform types than do the individual species. Vegetation types occurring predominantly with, or closely associated with, specific landform types, were summarized earlier, on page 186.

The vegetation types have a fair association with slope angles. Eight vegetation types occur predominantly on sites with low slope angles (less than 10%), eight vegetation types occur predominantly on sites with middle slope angles (11 - 25%), and nine vegetation

types occur predominantly on higher slope angles (greater than 25%). The Sporobolus wrightii type (21), the Bouteloua spp. (without Nolina microcarpa) type (18), and the Hilaria mutica type (22) occur predominantly on sites with very low slope angles, while the Aloysia wrightii type (12), the Quercus spp./ Arctostaphylos pungens with Mimosa biuncifera type (25), the Prosopis juliflora /Bouteloua spp. with Quercus spp. type (16), the Mortonia scabrella type (14), and the Cercocarpus breviflorus type (23) occur on the steepest slopes.

Closer associations were discovered between vegetation types and slope aspect than between species and slope aspect. Six vegetation types occur primarily on slopes with southerly aspects while eight vegetation types occur primarily on slopes with northerly aspects. The Bouteloua spp. /Fouquieria splendens type (31) occur on the most southerly slope aspects of the sampled sites, while the Bouteloua spp. /Nolina microcarpa type (17), the Cercocarpus breviflorus type (23), and the Prosopis juliflora /Bouteloua spp. with Quercus spp. type (16) occur almost exclusively on slopes with northerly aspects.

Six vegetation types have close relationships with low solar radiation index values while seven vegetation types have close relationships with high solar radiation index values.

Table 20 lists the degree and type of relationships existing between each vegetation type and each terrain variable in much the

Table 20. Summary of relationships between vegetation types and terrain variables based upon subjective evaluation of the data availabe. Numerical entries 1 through 5 correspond respectively to values of poor, fair, moderate, good, and excellent relationship.

Vegetation type	Ele-vation	Parent Material	Slope Aspect	Slope Angle	Solar Radiation	Land-form	Macro-relief	Drainage Density	Summary
2 = Latr*	5	5	1	4	3	4	4	4	4
3 = Cemi	5	3	4	3	4	3	3	4	4-
6 = Opun	2	5	2	4	4	4	4	3	3+
7 = Prju	4	5	2	4	3	4	4	1	3
8 = Caer	3	4	4	3	4	2	3	3	3
9 = Acco	3	4	3	3	3	3	3	3	3
10 = Acve	3	5	1	2	3	3	3	1	2+
11 = Rhus	4	5	4	2	4	4	3	1	3+
12 = Alwr	2	3	2	4	2	4	4	3	3
14 = Mosc	3	5	2	4	2	5	5	4	4
15 = PrBo	4	4	3	2	1	2	2	3	3-
16 = PrBQ	3	3	4	4	4	2	3	2	3
17 = BoNo	5	3	5	4	5	2	3	4	4
18 = Bout	4	5	4	4	3	3	3	3	3+
19 = BoYu	4	4	4	3	1	4	2	2	3
21 = Spwr	4	5	2	5	4	4	5	3	4
22 = Himu	3	5	2	4	4	4	4	3	4
23 = Cebr	5	4	5	5	5	4	5	4	5
24 = QuAr	4	4	3	4	3	4	3	4	3+
25 = QAMi	3	3	4	4	4	4	4	2	3+
26 = Come	5	4	3	4	1	5	5	4	4
27 = QuMi	3	3	3	3	4	2	4	2	3
29 = Ripa	3	4	3	3	3	4	2	2	3+
30 = QuNo	3	4	1	4	3	4	3	3	3
31 = BoFo	3	4	5	2	3	2	1	1	2+

*The symbols for the vegetation types are an abbreviation of the principal species characterizing the vegetation type. A full list of the vegetation types is given on Table 10.

same manner as the table illustrating the relationships between individual plant species and terrain variables (see Table 19). To summarize relationships between terrain variables and vegetation types, a highly generalized cross-section of terrain utilizing the terrain variables employed is presented in Figure 61.

The use of stepwise discriminant analysis to analyze relationships between terrain variables and vegetation types was most illuminating and accomplished two things. It determined which terrain variables were the best discriminants of vegetation types. It also determined which field sample sites (or observations), placed by the vegetation classification into a particular vegetation type, have terrain variables most like that vegetation type, and which field sample sites belonging to that particular vegetation type have terrain variables more like other types.

The terrain variables which are found to best discriminate vegetation types are in order: elevation, macrorelief, solar radiation, drainage density, and parent material.

What is ultimately hoped for in this type of study is a set of terrain variables which are sufficient in themselves to enable accurate inferential identification of vegetation types. One of the methods for enabling inferential identification of vegetation types is through the use of stepwise discriminant analysis. It is theoretically possible that one terrain variable would perfectly discriminate the

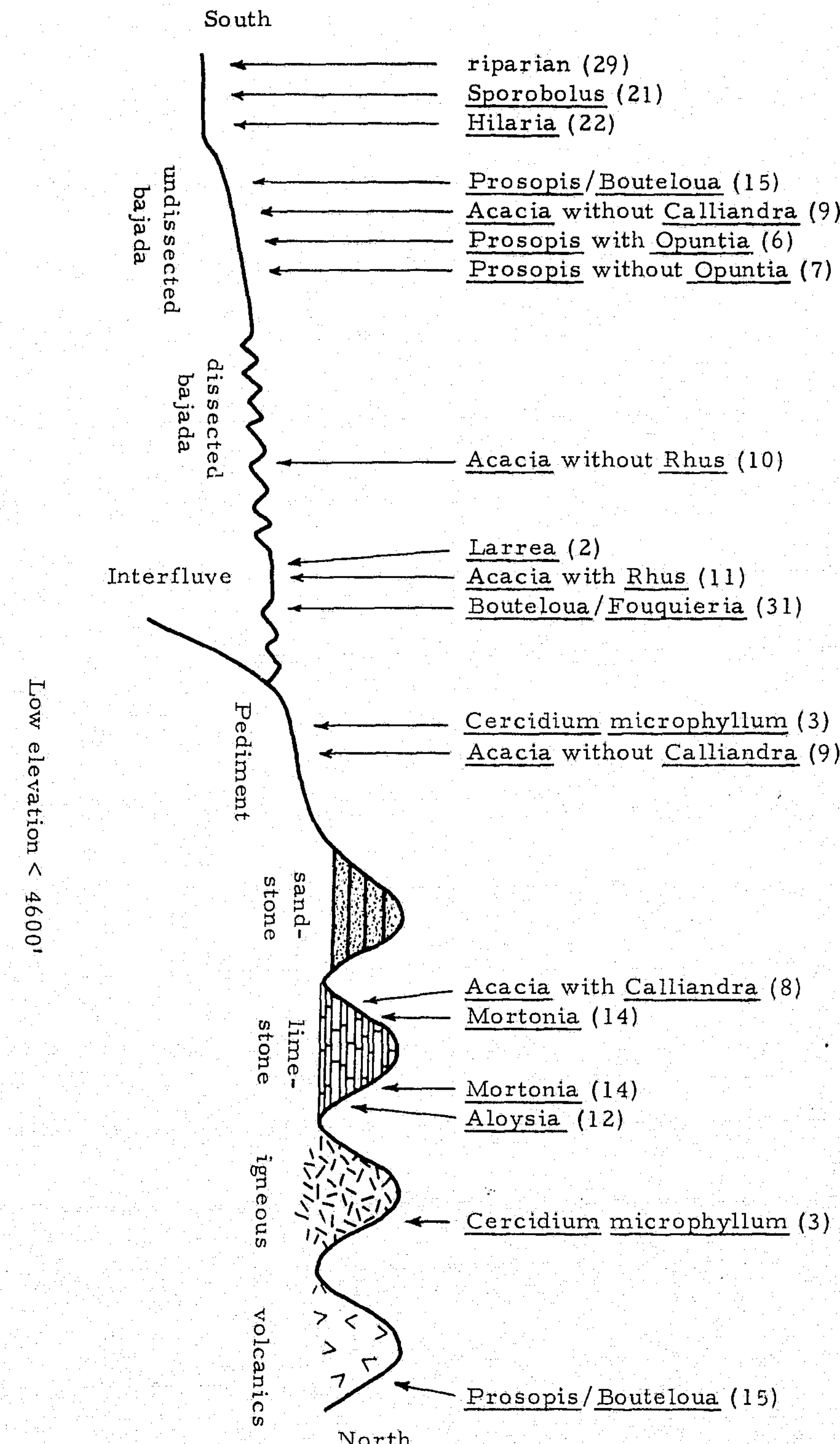
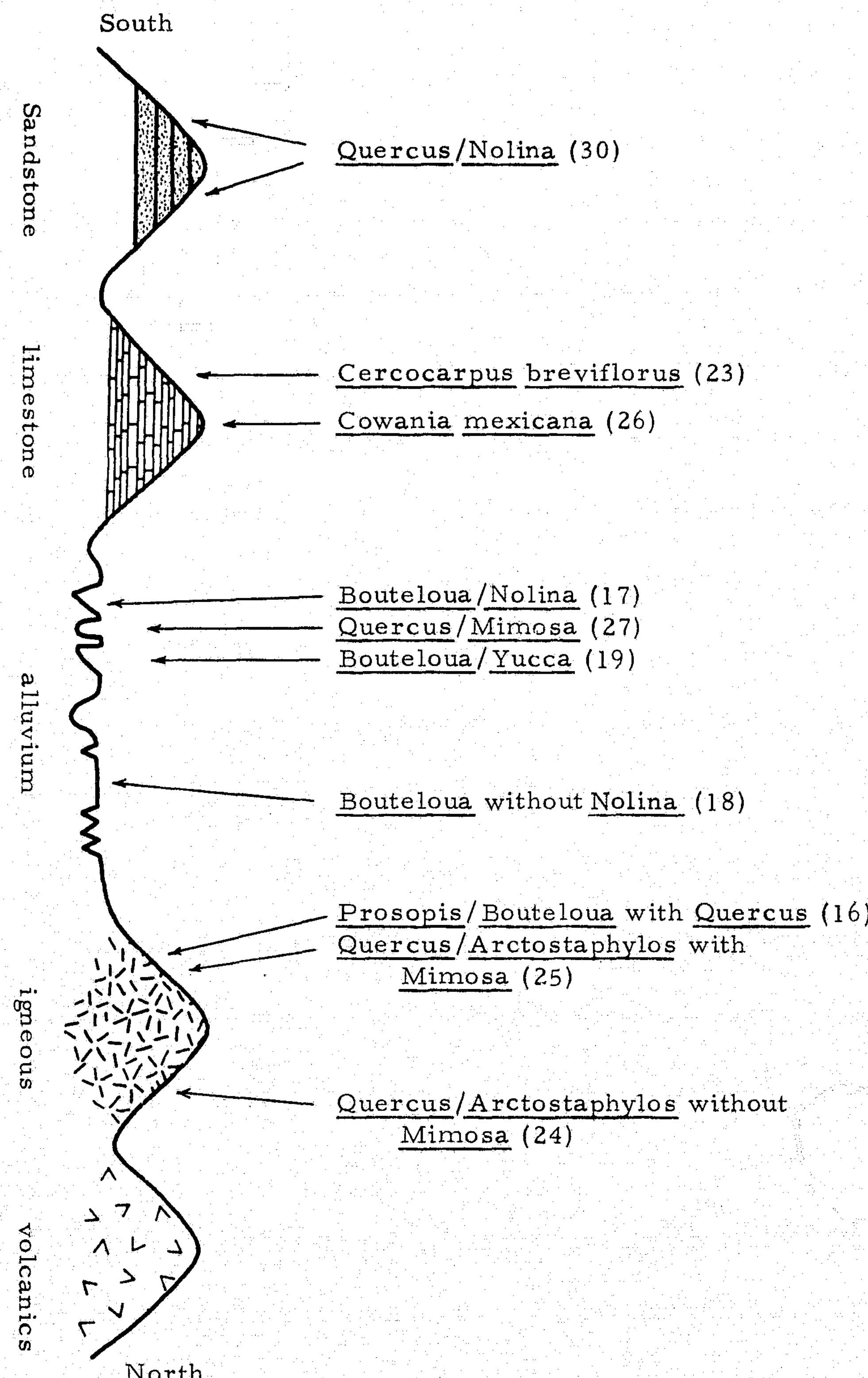


Figure 61. Highly generalized cross section of terrain indicating typical vegetation type occurrences.



High elevation > 4600'

Figure 61. Continued

vegetation types. However, in this study, that was not the case. In fact, all eight terrain variables interacting together did not perfectly discriminate the twenty-five vegetation types. Part of the reason for the "failure" was the similarity among vegetation types. Different vegetation types might represent different successional stages of similar habitat types, for example, and thus result in sets of terrain variables being nearly identical for two different seral types. Another reason for the failure of the eight terrain variables to perfectly discriminate the twenty-five vegetation types is that those terrain variables did not include all of the important environmental variables which result in differences in vegetation distribution.

Thus while relationships have been shown to exist between plant species and terrain variables, and between vegetation types and terrain variables, they are not perfect relationships. Perfect relationships probably do not exist. A better understanding, however, of other vegetation considerations (such as succession) and of other environmental variables might result in an apparent increase in observed relationships.

BIBLIOGRAPHY

Agricultural Research Service. 1967. Walnut Gulch experimental watershed. Soil and Water Conservation Research Division. U.S. Department of Agriculture. (In cooperation with the U.S. Soil Conservation Service, University of Arizona, and local ranchers.) Unnumbered leaflet. October, 1967. 28 pp. Illus.

Aldous, A. E., and H. L. Shantz. 1924. "Types of vegetation in the semi-arid portion of the United States and their economic significance." J. of Agricultural Research, 28:99-127.

Antevs, E. 1952. "Arroyo-cutting and filling." J. of Geology, LX: 375-385.

Arizona Bureau of Mines. 1959. Geologic map of Cochise County, Arizona. Tucson, The University of Tucson.

Bailey, R. W. 1935. "Epicycles of erosion in the valleys of the Colorado Plateau Province." J. of Geology, XLIII: 337-355.

Becking, R. W. 1957. The Zurich-Montpellier School of Phytosociology. The Botanical Review, 23:411-488.

Benson, L. 1969. The cacti of Arizona. Third edition. Tucson, University of Arizona press. 218 pp.

Benson, L., and R. A. Darrow. 1954. The trees and shrubs of the southwestern deserts. Second edition. Tucson, Albuquerque, University of Arizona press and University of New Mexico press. 437 pp.

Benson, M. A. 1964. Factors affecting the occurrence of floods in the southwest. U.S. Geological Survey, Water-Supply Paper 1580-D.

Blumer, J. C. 1912. "Notes on the phytogeography of the Arizona desert." Plant World, 15(8):183-9.

Bradbury, D. E. 1969. Vegetation as an indicator of rock types in the northern Swisshelm Mountains, southeastern Arizona. Tucson, University of Arizona (unpublished Masters' thesis). 133 pp.

Braun-Blanquet, J. 1964. Pflanzensoziologie. Grundzüge der vegetationskunde. . Wein, Springer-Verlag. 865 pp.

Bryan, K. 1925. Date of channel trenching (arroyo cutting) in the arid Southwest. Science, N.S., 62:338-344.

__________ 1926. "San Pedro Valley, Arizona, and the geographic cycle (abs.)." Geological Society of America, Bulletin, 57:169-170.

__________ 1928. "Change in plant associations by change in ground water level." Ecology, IX 474-478.

Buffington, L. C., and C. H. Herbel. 1965. "Vegetational changes on a semi-desert grassland range from 1858-1963." Ecological Monographs, 35(2):139-164.

Bull, W. B. 1964. Geomorphology of segmented alluvial fans in western Fresno County, California. U.S. Geological Survey, Professional Paper 352-E.

Bunting, B. T. 1965. The geography of soil. Chicago, Aldine Publishing Co., 213 pp.

Buol, S. W. 1966. "Soils of Arizona." Tucson. 25 p. and map. University of Arizona, Agricultural Experiment Station. Technical Bulletin 171.

Butzer, K. W. 1961. "Climatic changes in arid regions since the Pliocene." In: A history of land use in arid regions. UNESCO, Paris, France. Arid Zone Research, 17:31-56.

Cain, S. A. 1950. "Life-forms and phytoclimate." Botanical Review, 16(1):1-32.

Cannon, W. A. 1911. The root habits of desert plants. Carneggie Institute of Washington, Publication 131. 96 pp.

Cooley, M. E. 1967. Arizona Highway Geological Map. Tucson, Arizona Geological Society.

__________ 1968. "Some notes on the late Cenozoic drainage patterns in southeastern Arizona and southwestern New Mexico." In: Arizona Geological Society Guidebook.III. Edited by Titley, S. R. Tucson, University of Arizona, Arizona Geological Society. pp. 75-78.

Cooley, M. E. 1971. Physiography of southern Arizona. Tucson, U.S. Geological Survey, Water Resources Division. Unpublished map.

Cottle, H. J. 1932. "Vegetation of northern and southern slopes in mountains of southwest Texas." Ecology, 13(2):121-134.

Cumming, K. J. 1952. The effect of slope and exposure on range vegetation in desert grassland and oak woodland areas of Santa Cruz County, Arizona. M. S. Thesis. University of Arizona.

Darrow, R. A. 1944. "Arizona range resources and their utilization. I. Cochise County." Tucson, University of Arizona, Agricultural Experiment Station. Technical Bulletin 103.

Daubenmire, R. 1966. "Vegetation: Identification of typal communities." Science, 151:291-298.

Daubenmire, R. 1968. Plant Communities. New York, Harper and Row, Publishers. 300 pp.

Dice, L. P. 1939. "The Sonoran biotic province." Ecology, 20(2): 118-129.

Dick-Peddie, W. A. 1966. "Changing vegetation patterns in southern New Mexico." New Mexico Geological Society, 16th Field Conference, pp. 234-235.

Fenneman, N. M. 1931. Physiography of the western United States. New York, McGraw-Hill. 534 pp.

Ffolliott, P. F., D. L. Fisher, and D. B. Thorud. 1972. "A physiographic survey of the ponderosa pine type on the Salt-Verde River basin." Tucson, University of Arizona, Agricultural Experiment Station. Technical Bulletin 200. 60 pp.

Frank, E. C., and R. Lee. 1966. "Potential solar beam irradiation on slopes: tables for 30° to 50° latitude." Rocky Mountain Forest and Range Experiment Station. U.S. Forest Service Research Paper RM-18. 116 pp.

Garcia-Moya, E. 1972. A preliminary vegetation classification of the Tombstone, Arizona, Vicinity. Doctoral dissertation. Corvallis, Oregon State University. 195 pp.

Geiger, R. 1965. The climate near the ground. Fourth edition. Harvard University Press. Boston, Massachusetts. 611 pp.

Gelderman, F. W., and P. Tripp. 1970. Soil survey of Walnut Gulch experimental watershed, Arizona. A special report. Portland. 55 pp. (U.S. Department of Agriculture. Soil Conservation Service and Agricultural Research Service in cooperation with the Arizona Agricultural Experiment Station.)

Gile, L. H., and R. B. Grossman. 1968. "Morphology of the argillic horizon in desert soils of southern New Mexico." Soil Science, 106:6-15.

Gile, L. H., and J. W. Hawley. 1966. "Periodic sedimentation and soil formation on an alluvial-fan piedmont in southern New Mexico." Soil Science Society of American Proceedings, 30:261-268.

Gile, L. H., J. W. Hawley, and R. B. Grossman. 1971. The identification, occurrence, and genesis of soils in an arid region of southern New Mexico. U.S. Department of Agriculture, Soil Conservation Service, Soil Survey Investigations, (Training sessions, Desert Soil-Geomorphology Project, Dona Ana County, New Mexico), 177 p.p. (with 199 pp. of soil type descriptions).

Gile, L. H., F. F. Peterson, and R. B. Grossman. 1965. "The K horizon: A master horizon of carbonate accumulation." Soil Science 99:74-82.

Gilluly, J. 1958. "General geology of central Cochise County, Arizona." U.S. Geological Survey, Professional Paper 281. 169 pp.

Goff, F. G., and G. Cottam. 1967. "Gradient analysis - the use of species and synthetic indices." Ecology 48:793-806.

Gould, F. W. 1951. "Grasses of southwestern United States." Tucson, University of Arizona Press. Biological Science Bulletin No. 7. 343 pp.

Green, C. R., and W. D. Sellers (editors). 1964. Arizona Climate. Tucson, University of Arizona Press. 503 pp.

Griffiths, D. 1910. A protected stock range in Arizona. U.S. Department of Agriculture, Bureau of Plant Industries Bulletin 177, 28 pp.

Haase, E. F. 1970. Environmental fluctuations on south-facing slopes in the Santa Catalina mountains of Arizona. Ecology, V. 51, No. 6. pp. 959-974.

Hastings, J. R. 1959. "Vegetation change and arroyo-cutting in southeastern Arizona." J. Arizona Academy of Sciences, 1:60-67.

Hastings, J. R. and R. M. Turner. 1965. The Changing Mile. An ecological study of vegetation change with time in the lower mile of an arid and semi-arid region. Tucson, University of Arizona Press. 317 pp.

Hastings, J. R., R. M. Turner, and D. K. Warren. 1972. "An atlas of some plant distributions in the Sonoran desert." Tucson, University of Arizona, Institute of Atmospheric Physics Technical Reports on the Meteorology and Climatology of Arid Lands, No. 21. 255 pp.

Haynes, C. V. 1968. "Preliminary report on the late Quaternary geology of the San Pedro Valley, Arizona." In: Arizona Geological Society Guidebook III. Edited by Titley, S. R., Tucson, University of Arizona, Arizona Geological Society. pp. 79-96.

Hendricks, D. M., and Y. H. Havens. 1970. Desert soils tour guide. Tucson, Soil Science Society of America. 58 pp.

Humphrey, R. R. 1953. Desert grassland, past and present. J. of Range Management, 6:159-164.

__________ 1958. "The desert grassland, a history of vegetational change and an analysis of causes." Botanical Review, 24:193-252.

__________ 1960. Forage production on Arizona ranges. V. Pima, Pinal, and Santa Cruz counties. Tucson, University of Arizona, Agricultural Experiment Station Bulletin 302.

Humphrey, R. R. 1963. "Arizona natural vegetation." Tucson, University of Arizona, Agricultural Experiment Station and Cooperative Extension Service, Bulletin A-45.

Humphrey, R. R. 1970. "Arizona range grasses." Tucson, University of Arizona Press. 1960 pp.

Humphrey, R. R., and L. A. Meyerhoff. 1958. "Vegetation changes on a southern Arizona grassland range." Ecology. 39:720-726.

Interagency Technical Committee (Range), The. 1963. Vegetative units of the major land resource areas, Arizona. Portland. 19 pp. and map. (University of Arizona, Agricultural Extension Service, Agricultural Research Service, Soil Conservation Service.)

Ives, R. L. 1949. "Climate of the Sonoran desert region." Annals of AAG, 39:143-187.

Jaeger, E. C. 1957. The North American Deserts. Stanford University Press. 308 pp.

Jenny, H. 1941. Factors of Soil Formation. New York, McGraw-Hill.

Jones, R. W. 1966. "Differential vertical uplift - a major feature in the structural evolution of southeast Arizona." Arizona Geological Society Digest, VIII:97-124.

Kassas, M. 1952. "Habitat and plant communities in the Egyptian desert, I: Introduction." J. of Ecology, 40(2):342-351.

________________ 1953. "Habitat and plant communities in the Egyptian desert, II: The features of a desert community." J. of Ecology, 41(2):248-256.

________________ 1956. "Landforms and plant cover in the Omdurman desert, Sudan." Société de Géographie d'Egypt Bull. 29:43-53.

Kassas, M. 1957. "On the ecology of the Red Sea coastal land." Jour. Ecology 45:187-203.

________________ 1959. "Habitat and plant communities in the Egyptian desert, IV: The gravel desert." J. of Ecology, 47:289-310.

________________ 1960. "Certain aspects of landform effects on plant/water resources." Société de Géographie d'Egypt Bull. 33:45-51.

Kassas, M. 1961. "Certain aspects of landform effects on plant/water resources." In: Plant/Water Relationships in Arid and Semi-Arid Conditions, a symposium. UNESCO, Paris, France. Arid Zone Research 16:71-78.

__________ 1966. "Plant life in deserts." In: Arid Lands, a Geographical Appraisal, E. S. Hills, editor. Methuen and Co. Ltd., London; UNESCO, Paris, France. pp. 145-180.

Kassas, M. and M. S. El-Abyad. 1962. "On the phytosociology of the desert vegetation of Egypt." Ann. Arid Zone 1:54-83.

Kassas, M., and W. A. Girgis. 1964. "Habitat and plant communities in the Egyptian desert. V: The limestone plateau." J. of Ecology, 52(1):107-119.

__________ 1965. "Habitat and plant communities in the Egyptian desert. VI. The units of a desert ecosystem." J. of Ecology 53:715-728.

__________ 1970. "Habitat and plant communities in the Egyptian desert. VII: Geographical facies of plant communities. J. of Ecology, 58(2): 335-350.

Kassas, M., and M. Imam. 1954. "Habitat and plant communities in the Egyptian desert. III: The wadi bed ecosystem." J. of Ecology, 42(2):424-441.

__________ 1959. "Habitat and plant communities in the Egyptian desert. IV. The gravel desert." J. of Ecology 47:289-310.

Kearney, T. H., and R. H. Peebles. 1964. Arizona Flora. Second edition, with supplement by J. T. Howell and E. McClintock. Berkeley, University of California Press. 1085 pp.

Kottlowski, F. E., M. E. Cooley, and R. V. Ruhe. 1965. "Quaternary geology of the southwest." In: The Quaternary of the United States. Edited by Wright, H. E. Jr., and D. G. Frey. Princeton, The Princeton University Press. pp. 287-298.

Kuchler, A. W. 1964. Potential natural vegetation of the conterminous United States. American Geographical Society. New York. Special publication, No. 36. 116 pp.

Lee, R. 1963. "The 'topographic' sampler." J. of Forestry, 61:922-923.

Little, E. O. 1950. "Southwestern trees, a guide to the national species of New Mexico and Arizona." U.S. Department of Agriculture, Agricultural Handbook, 99:1-109.

Lowe, C. H. 1961. "Biotic communities in the Sub-Mogollon region of the inland Southwest." J. Arizona Academy of Science. 2:40-49.

__________ 1964. The vertebrates of Arizona. Tucson, The University of Arizona Press, 270 pp.

Martin, P. S. 1963. The last 10,000 years: A follis-pollen record of the American southwest. Tucson, University of Arizona Press. 78 pp.

Matlock, W. G., and P. R. Davis. 1972. Groundwater in the Santa Cruz Valley. Tucson, The University of Arizona. Agricultural Experiment Station Technical Bulletin 194, 37 pp.

McGinnies, William G. 1968. "Vegetation of desert environments." In: Deserts of the World. Edited by McGinnies, Goldman, and Paylore. Tucson, University of Arizona Press. pp. 381-566.

McIntosh, R. P. 1967. "The continuum concept of vegetation." Botanical Review, 33:130-187.

Melton, M. A. 1959-1960. "Origin of the drainage and geomorphic history of southeastern Arizona." Tucson, University of Arizona, Arid Lands Colloquia. pp. 8-16.

__________ 1965. "The geomorphic and paleoclimatic significance of alluvial deposits in southern Arizona." J. Geology 73:1-38.

Merriam, C. H. 1890. Results of a biological survey of the San Francisco Mountains region and the desert of the Little Colorado in Arizona. U.S. Department of Agriculture, No. American Fauna 3:1-136.

Morrison, R. B. 1972. A test and evaluation of SKYLAB (EREP) data applications to a present-status inventory of the post-1890 A. D. episode of accelerated erosion, and to monitoring future erosional changes, with specific reference to the Arizona Regional Ecological Test Site (ARETS). A proposal submitted to the National Aeronautics and Space Administration, Washington, D. C. 37 pp.

Mouat, D. A. 1972. "Terrain feature-vegetation relationships in southern Arizona." In: Proceedings of the International Conference on Remote Sensing of Arid Lands. Tucson, University of Arizona.

Nichol, A. A. 1937, revised 1952. "The natural vegetation of Arizona." University of Arizona, Agricultural Experiment Station. Teaching bulletin 68:181-222. 1952 bulletin, 127: 186-230.

Niering, W. A., R. H. Whittaker, and C. H. Lowe. 1963. "The Saguaro, a population in relation to environment." Science, 142(3588):15-23.

Nikiforoff, C. C. 1937. "General trends of the desert type of soil formation." Soil Science 43:105-131.

Norris, J. M., and J. P. Barkham. 1970. "A comparison of some Cotswold Beechwoods using multiple-discriminant analysis." J. Ecology 58(3):603-619.

Phillips, E. A. 1959. Methods of Vegetation Study. Henry Holt and Company. 107 pp.

Poulton, C. E., D. P. Faulkner, and N. L. Martin. 1971. A Procedural Manual for resource analysis-application of ecology and remote sensing in the analysis of range watersheds. Final project report. U.S. Department of the Interior, Bureau of Land Management (Portland, Oregon,) Corvallis, Oregon State University, Agricultural Experiment Station. Range Management Program. 97 pp., with appendices.

Poulton, C. E., et al. 1970. "High altitude photography in the analysis of natural vegetation resources with implications in land use." In: Pettinger, L. R., et al. The application of high altitude photography for vegetation resource inventories in southeastern Arizona. (Final report, National Aeronautics and Space Administration, Contract NAS 9-9577, Earth Observations Division, MSC, Houston). pp. 56-147.

Poulton, C. E., J. R. Johnson, and D. A. Mouat. 1970. Inventory of native vegetation and related resources from space photography. (Annual Progress Report to the National Aeronautics and Space Administration, Contract R-09-038-002, Earth Resources Program, Houston). 33 pp.

Pyott, W. T. 1972. Numerical classification of range vegetation and statistical analysis of its ecology. Doctoral dissertation. Corvallis, Oregon State University. 238 pp.

Renard, K. G. 1970. The hydrology of semi-arid rangeland watersheds. U.S. Department of Agriculture, Agricultural Research Service, ARS 41-162. 26 pp.

Reynolds, H. G., and J. W. Bohning. 1956. "Effects of burning on a desert grass-shrub range in southern Arizona." Ecology, 37(4):769-777.

Richardson, M. L. 1971. General soil map of Santa Cruz County, Arizona. Portland. U.S. Department of Agriculture, Soil Conservation Service. 14 pp.(map).

Robison, J. W. 1958. "Phreatophytes." U.S. Geological Survey, Water-Supply Paper 1432. 84 pp.

Runyon, E. H. 1934. "The organization of the creosotebush with respect to drought." Ecology, 15(2):128-138.

Sampson, P. 1968. BMDO7M. Stepwise discriminant analysis. In: BMD Biomedical computer programs, Edited by W. J. Dixon. Los Angeles, University of California Publication in Automatic Computations No. 2, p. 214 a-1.

Schallig, W. H. C. 1967. The preparation of association tables and the science of modern phytosociology, Part I. Corvallis, Oregon State University. Range Management Program. 46 pp.

Schrumpf, B. J., J. R. Johnson, and D. A. Mouat. 1973. Inventory and monitoring of natural vegetation and related resources in an arid environment - A comparative evaluation of ERTS-1 imagery. (Type II Progress Report for period September 1, 1972 to February 28, 1973 prepared for NASA. Contract NAS 5-21831, Goddard Space Flight Center, Greenbelt, MD.) 42 pp.

Segura-Bustamante, M. 1970. Ecology of bitterbrush (Purshia tridentata [Pursh] DC) in the Silver Lake deer winter range, Oregon. Doctoral dissertation. Corvallis, Oregon State University. 442 pp.

Shantz, H. L. 1927. "Drought resistance and soil moisture." Ecology, 8(2):145-157.

_______________ 1938. "Plants as soil indicators." In: Soils and Men. U.S. Department of Agriculture, Yearbook. pp. 835-860.

Shantz, H. L., and R. L. Piemeisel. 1924. "Indicator significance of the natural vegetation of the southwestern desert region." J. of Agricultural Research, 28(8):721-801.

Shreve, F. 1915. "The vegetation of a desert mountain range as conditioned chiefly by climatic factors." Carneggie Institution of Washington, Publication 217. 112 pp.

_______________ 1922. "Conditions indirectly affecting vertical distribution on desert mountains." Ecology, 3(4):269-274.

_______________ 1924. "Soil temperature as influenced by altitude and slope exposure." Ecology 5:128-136.

Shreve, F. 1925. "Ecological aspects of the deserts of California." Ecology, 6(2):93-103.

_______________ 1936. "The plant life of the Sonoran Desert." Scientific Monthly, 42:195-213.

_______________ 1942a. "The desert vegetation of North America." Botanical Review, 8(4):195-246.

Shreve, F. 1942b. "The vegetation of Arizona." U.S. Department of Agriculture. Miscellaneous Publication No. 423:10-23.

Shreve, F., and T. D. Mallery. 1933. "The relation of caliche to desert plants." Soil Science, 35(2):99-113.

Shreve, F., and I. L. Wiggins. 1964. Vegetation and flora of the Sonoran Desert. Stanford, Stanford University Press. Two volumes.

Smith, B. R., and S. W. Buol. 1968. "Genesis and relative weathering studies in three semi-arid soils." Soil Science Soc. of Amer. Proc. 32:261-265.

Smith, H. V. 1956. "The climate of Arizona." Tucson, University of Arizona, Arizona Agricultural Experiment Station. Bulletin 279. 99 pp.

Soil Conservation Service. Soil series descriptions. 52 looseleaf pages.

Soil Survey Staff. 1970. Soil Classification: A comprehensive system, 7th approximation. U. S. Department of Agriculture, Soil Conservation Service.

Spalding, V. M. 1909. "Distribution and Movements of desert plants." Carneggie Institute of Washington, Publication 113. 144 pp.

Thornber, J. J. 1907. Destruction of range weeds. Tucson, University of Arizona, Agricultural Experiment Station 18th Annual Report. 228 pp.

__________ 1909. "Relation of plant growth and vegetation forms to climatic conditions." Plant World 12(1):1-7.

__________ 1910. "The grazing ranges of Arizona." Tucson, University of Arizona, Arizona Agricultural Experiment Station. Bulletin 65. pp. 246-360.

Tuan, Yi-Fu. 1959. Pediments in southeastern Arizona. Berkeley, University of California Publications in Geography. Vol. 13. 163 pp.

__________ 1962. "Structure, climate, and basin landforms." Annals of the Association of American Geog. 52:51-68.

Wallmo, O. C. 1955. "Vegetation of the Huachuca Mountains, Arizona." American Midland Naturalist, 54(2):466-480.

Whittaker, R. H. 1967. "Gradient analysis of vegetation." Biological Review, 42:207-264.

Whittaker, R. H., and W. A. Niering. 1965. "Vegetation of the Santa Catalina Mountains, Arizona. 1. Ecological classification and distribution of species." J. of the Arizona Academy of Science, 3:9-33.

Whittaker, R. H., and W. A. Niering. 1965. "Vegetation of the Santa Catalina Mountains, Arizona: A gradient analysis of the south slope." Ecology, 46:429-452.

______________ 1968. "Vegetation of the Santa Catalina Mountains, Arizona. III. Species distribution and floristic relations on the north slope." J. of the Arizona Academy of Science, 5:3-21.

______________ 1968. "Vegetation of the Santa Catalina Mountains, Arizona. IV. Limestone and acid soils." J. of Ecology, 56:523-544.

Wilson, E. D. 1962. "A resume of the geology of Arizona." Arizona Bureau of Mines, Bulletin 171. Tucson, University of Arizona. 140 pp.

Wilson, E. D., R. T. Moore, and R. T. O'Haire. 1960. Geologic map of Pima and Santa Cruz Counties, Arizona. Tucson, University of Arizona, Arizona Bureau of Mines.

Yang, T. W., and C. H. Lowe, Jr. 1956. "Correlation of main vegetation climaxes with soil characteristics in the Sonoran Desert." Science, 123-542.

Zimmermann, R. C. 1969. Plant ecology of an arid basin, Tres Alamos-Redington area, southeastern Arizona. U. S. Geological Survey Professional Paper 485-D, 51 pp.

APPENDIX I

Plant Species List

Scientific names are from Kearney and Peebles (1964) and Benson (1969). Common names are from Benson (1969), Benson and Darrow (1954), and Kearney and Peebles (1964).

Growth Form	Scientific Name	Common name
Trees	Arbutus arizonica	Arizona madrono
	Chilopsis linearis	Desert willow
	Cupressus arizonica	Arizona cyprus
	Eysenhardtia polystachya	Kidneywood
	Fraxinus velutina	Arizona ash
	Juglans major	Arizona walnut
	Juniperus deppeana	Alligator juniper
	J. monosperma	One-seed juniper
	Pinus cembroides	Mexican Pinyon
	P. engelmannii	Apache pine
	P. leiophylla	Chihuahua pine
	P. ponderosa	Ponderosa pine
	Platanus wrightii	Arizona sycamore
	Populus fremontii	Fremont cottonwood
	P. tremuloides	Quaking aspen
	Pseudotsuga menziesii	Douglas fir
	Quercus arizonica	Arizona white oak
	Q. emoryi	Emory oak
	Q. gambelii	Gambel oak
	Q. hypoleucoides	Silverleaf oak
	Q. oblongifolia	Mexican blue oak
	Q. rugosa	Net-leaf oak
	Q. toumeyi	Toumey oak
	Robinia neomexicana	New Mexican
Shrubs and Half Shrubs	Acacia constricta	Whitethorn acacia
	A. greggii	Catclaw acacia
	A. millefolia	Santa Rita acacia
	A. vernicosa	Mescat acacia
	Aloysia wrightii	Wright's lippia
	Amorpha fruticosa	Indigo-bush
	Anisacanthus thurberi	Chuparose, Desert-honeysuckle
	Arctostaphylos pungens	Manzanita
	Atriplex canescens	Four-wing, Saltbush, Chamiso
	A. linearis	Saltbush
	Baccharis brachyphylla	Baccharis
	B. glutinosa	Batamote, Seep, Willow
	B. pteronioides	Yerba de pasmo
	B. sarothroides	Desert broom
	Bernardia incana	Bernardia
	Brayulinea densa	
	Brickellia spp.	

Appendix I (cont.)

Growth Form	Scientific Name	Common Name
Shrubs and Half Shrubs (cont.)	Calliandra eriophylla	Huajillo, Fairy duster
	Ceanothus greggii	Wild lilac
	Celtis pallida	Desert Hackberry
	C. reticulata	Western hackberry
	Cercidium floridum	Blue paloverde
	C. microphyllum	Foothill paloverde
	Cercocarpus breviflorus	Mountain mahogany
	Choysia dumosa	Star leaf, Mexican orange
	Clematis ligustifolia	Virgin's bower
	Coldenia canescens	
	Condalia lycioides	Graythorn
	C. spathulata	Mexican crujillo
	Cowania mexicana	Cliff-rose, Quinine bush
	Desmanthus cooleyi	
	Encelia farinosa	Incienso, Brittle bush
	Ephedra trifurca	Mormon tea
	Eriogonum wrightii	Wild buckwheat
	Erythrina flabelliformus	Chilicote, Deadly coral bean
	Flourensia cernua	Tarbush, Blackrush
	Fouquieria splendens	Ocotillo
	Franseria dumosa	White bursage
	Garrya wrightii	Silk-tassel
	Gutierrezia lucida	
	G. sarothrae	Snakeweed
	Haplopappus laricifolius	Turpentine bush
	H. tenuisectus	Burroweed
	Hibiscus denudatus	Rose-mallow
	Koeberlinia spinosa	Crucifixion thorn
	Krameria parvifolia	Ratany
	Larrea tridentata	Creosote bush
	Lycium spp.	Desert thorn
	Menodora scabra	Broom menodora
	M. dysocarpa	Velvet-pod mimosa
	Mimosa biuncifera	Wait-a-minute bush
	Mortonia scabrella	Sandpaper bush
	Parthenium incanum	Mariola
	Prosopis juliflora	Mesquite
	Rhus choriophylla	Sumac
	R. microphylla	Sumac
	R. trilobata	Skunk-bush, Squaw-bush
	Senecio spp.	Groundsel
	Tecoma stans	Trumpet flower
	Thamnosma texana	Cordoncillo, Turpentine broom
	Vauquelinia californica	Arizona rosewood
	Vitis arizonica	Canyon grape
	Zinnia pumila	Desert zinnia

Appendix I (Cont.)

Growth Form	Scientific Name	Common name
Leaf Succulents	Agave palmeri	Mescal
	A. parryi	Mescal
	A. schottii	Amole
	Agave spp.	Century plant
	(Agave spp. not including A. schottii = A. palmeri and A. parryi)	
	Dasylirion wheeleri	Sotol, Desert spoon
	Nolina microcarpa	Beargrass, Sacahuista
	Yucca baccata	Datil, Blue yucca
	Y. elata	Palmilla, Soaptree yucca
	Y. schottii	Mountain yucca
Stem Succulents	Cereus giganteus	Saguaro
	Echinocereus spp.	Hedgehog cactus
	Ferocactus wislizenii	Barrel cactus
	Mammillaria spp.	Fishhook or Pincushion cactus
	Opuntia arbuscula	Pencil cholla
	O. fulgida	Jumping cholla
	O. leptocaulis	Christmas cactus
	O. phaeacantha	Prickly pear
	O. spinosior	Cane cholla
	O. versicolor	Staghorn cholla
	O. violaceae	Purple prickly pear
Forbs	Amaranthus	Amaranth
	Anemone	Anemone
	Astragalus spp.	Milk-vetch, Loco weed, Poison vetch
	Brodiaea spp.	
	Cassia spp.	Senna
	Chenopodium spp.	Goosefoot
	Cnidoscolus angustidens	Mala-mujer
	Euphorbia spp.	Spurge
	Galium spp.	Bedstraw
	Lesquerella spp.	Bladder-pod
	Mentzelia spp.	Stick-leaf
	Perezia nana	Desert-holly
	Polypodium spp.	Rock fern
	Psilostrope cooperi	Paperflower
	Rumex lymenosepalus	Canaigre, Wild-rhubarb
	Salsola kali	Russian thistle
	Satellaria tesselata	
	Solanum spp.	Nightshade
	Sphaeralcea spp.	Globe-mallow
	Streptanthus spp.	Twist-flower
	Xanthium spp.	Cocklebur

Appendix I (Cont.)

Growth Form	Scientific Name	Common name
Grasses	Andropogon spp.	Bluestem
	A. barbinodis	
	A. cirratus	Texas bluestem
	A. scoparius	Little bluestem
	Aristida spp.	Threeawn
	Bouteloua barbata	Six-weeks grama
	B. chondrosioides	Sprucetop grama
	B. curtipendula	Sideoats grama
	B. eludens	Santa Rita grama
	B. eriopoda	Black grama
	B. gracilis	Blue grama
	B. hirsuta	Hairy grama
	B. rothrockii	Rothrock grama
	Chloris spp.	Fingergrass
	Distichlis stricta	Saltgrass
	Eragrostis spp.	Lovegrass
	Heteropogon contortus	Tanglehead
	Hilaria belangeri	Curly mesquite
	H. mutica	Tobosa
	Jatropha cardiophylla	Limber bush, Sangre de Cristo
	Jatropha macrorhiza	
	Leptochloa dubia	Green sprangletop
	Lycurus phleoides	Wolftail
	Muhlenbergia porteri	Bush muhly
	M. minutissima	
	M. montana	Mountain muhly
	Panicum spp.	Panic grass
	Scleropogon brevifolius	Burro grass
	Setaria macrostachya	Plains bristlegrass
	Sitanion hystrix	Squirreltail
	Sporobolus airoides	Alkali sacaton
	S. wrightii	Sacaton
	Trichachne californica	Cottontop
	Tridens pulchellus	Fluffgrass

APPENDIX II.

BMDO7M. Stepwise Discriminant Analysis

General Description (from Sampson, 1968)

a. This program performs a multiple discriminant analysis in a stepwise manner. At each step one variable is entered into the set of discriminating variables. The variable entered is selected by the first of the following equivalent criteria:

(1) The variable with the largest F value.
(2) The variable which when partialed on the previously entered variables has the highest multiple correlation with the groups.
(3) The variable which gives the greatest decrease in the ratio of within to total generalized variances.

A variable is deleted if its F value becomes too low. The program also computes canonical correlations and coefficients for canonical variables. It plots the first two canonical variables to give an optimal two-dimensional picture of the dispersion.

b. The output consists of:

(1) Group means and standard deviations
(2) Within groups covariance matrix
(3) Within groups correlation matrix
(4) At each step:
    (a) Variables included and F statistic to remove
    (b) Variables not included and F statistic to enter
    (c) U statistic and approximate F statistic to test equality of group means
    (d) Matrix of F statistics to test the equality of means between each pair of groups
(5) At certain specified steps and after the last step:
    (a) Discriminant functions
    (b) Classification matrix

(6) For each case:

(a) The posterior probability of coming from each group
(b) Square of the Mahalanobis distance from each group

(7) Summary table. For each step of the procedure the following is tabulated:

(a) Variable entered or removed
(b) F value to enter or remove
(c) Number of variables included
(d) U statistic

(8) Eigenvalues, canonical variables and coefficients of canonical variables are printed and, optionally, written on a tape. The number of canonical variables written on tape is equal to the number of original variables included in the last step.

(9) Plot of the first canonical variable against the second.

(10) Residuals and canonical coefficients (optional).

c. Limitations per problem:

(1) p, number of variables ($1 < p \leq 41$)
(2) t, total number of groups ($2 \leq t \leq 41$)
(3) j, number of Variable Format Card(s) ($1 \leq j \leq 16$)

This program was written by Paul Sampson, a member of the staff of Health Sciences computing facility, UCLA.

References

Anderson, T. W., Introduction to Multivariate Statistical Analysis, Wiley, 1958.

Efroymsen, M. A., Multiple Regression Analysis, In Mathematical Methods for Digital Computers, Part V, (17). Edited by A. Ralston and H. S. Wilf, Wiley, 1960.

Rao, C. R., Advanced Statistical Methods in Biometric Research, Wiley, 1962.